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MANUFACTURING METHODS AND TECHNOLOGY (MANTECH) PROGRAM: MANUFACTURING TECHNIQUES FOR A COMPOSITE MAIN ROTOR BLADE FOR THE ADVANCED ATTACK HELICOPTER

R. KIRALY
R.E. HEAD

Hughes Helicopters, Inc.

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Ballistic Survivability	Fabrication	Kevlar
		Nomex

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This manufacturing methods and technology program refined the design for a composite main rotor blade (CMRB) for the AH-64A advanced attack helicopter, perfected the fabrication technology for manufacturing it by wet filament winding process, and demonstrated it through laboratory tests and whirlstand tests. The CMRB replaces the equivalent metal main rotor blade with a weight saving of 24 pounds and a unit production cost saving of $194, 300 per shipset. Ballistic tolerance against 23mm HEI-T was

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demonstrated, and satisfactory erosion prctection and lightning protection methods were incorporated.

PREFACE

This report was prepared by Hughes Helicopters, Inc. (HHI) under U.S. Army Contract DAAK50-78-G-0004, Delivery Order 0003. The contract was sponsored by the U.S. Army Aviation Research and Development Command (AVRADCOM) and administered under the technical direction of Mr. James Tutka, AVRADCOM, with assistance from Mr. Harold Reddick, Applied Technology Laboratory, Ft. Eustis, VA.

The technical tasks were conducted at HHI under the direction of its program manager, Mr. Robert Kiraly.

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INTRODUCTION

The Composite Main Rotor Blade (CMRB) was the subject of one of a triad of Manufacturing Methods and Technology (MM&T) programs that AVRADCOM established to introduce advanced composites into the primary structure of the AH-64A Advanced Attack Helicopter (AAH), Figure 1, and to refine the techniques for manufacturing them. All were conducted under AVRADCOM Contract DAAK50-78-G-0004. The principal motivations for this MM&T work were the promise of reduced weight of the composite components relative to the prototype metal components; lower production cost; and improved survivability, reliability, and maintainability. In the case of the CMRB, weight reduction was not a significant requirement because a constant level of rotor inertia is needed for good autorotation. However, cost reduction was a primary goal.

The CMRB is designed to be a direct replacement for the metal main rotor blade that was developed for the AH-64A during its prototype phase. The planform, airfoil, twist, tip sweepback, and root-end attachment are identical to those of the metal blade, while its inertia and dynamic properties provide satisfactory performance on the AH-64A. The CMRB has a hybrid construction, being made of Kevlar 49, graphite, fiberglass, resin, Nomex honeycomb, stainless steel, and aluminum mesh. The wet filament winding (WFW) fabrication process that is used to the maximum extent feasible in this program is based on work that HHI has performed for the Army under contracts for the composite tail assembly and the multi-tubular spar (MTS) main rotor blade for the AH-1G, (Reference 1 and 2) and the composite trailing arm for the AH-64A landing gear (Reference 3).

All fabrication was done at HHI in its composites research laboratory. The major portion of the blade is assembled, shaped, and curved in a closed-cavity, self-heated mold. Minor trimming and finishing completes the manufacturing process. The blade has gone through static tests, fatigue tests,

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[1]Needham, J. F., USAAMRDL TR-76-24: Design, Fabrication, and Testing of an Advanced Composite AH-1G Tail Section (Tailboom/Vertical Fin), February 1976.

[2]Head, R.E., USAAMRDL TR-77-19: Flight Test of a Composite Multi-Tubular Spar Main Rotor Blade on the AH-1G Helicopter, August 1977.

[3]Goodall, R.E., USAAMRDL TR-77-27: Advanced Technology Helicopter Landing Gear, October 1977.

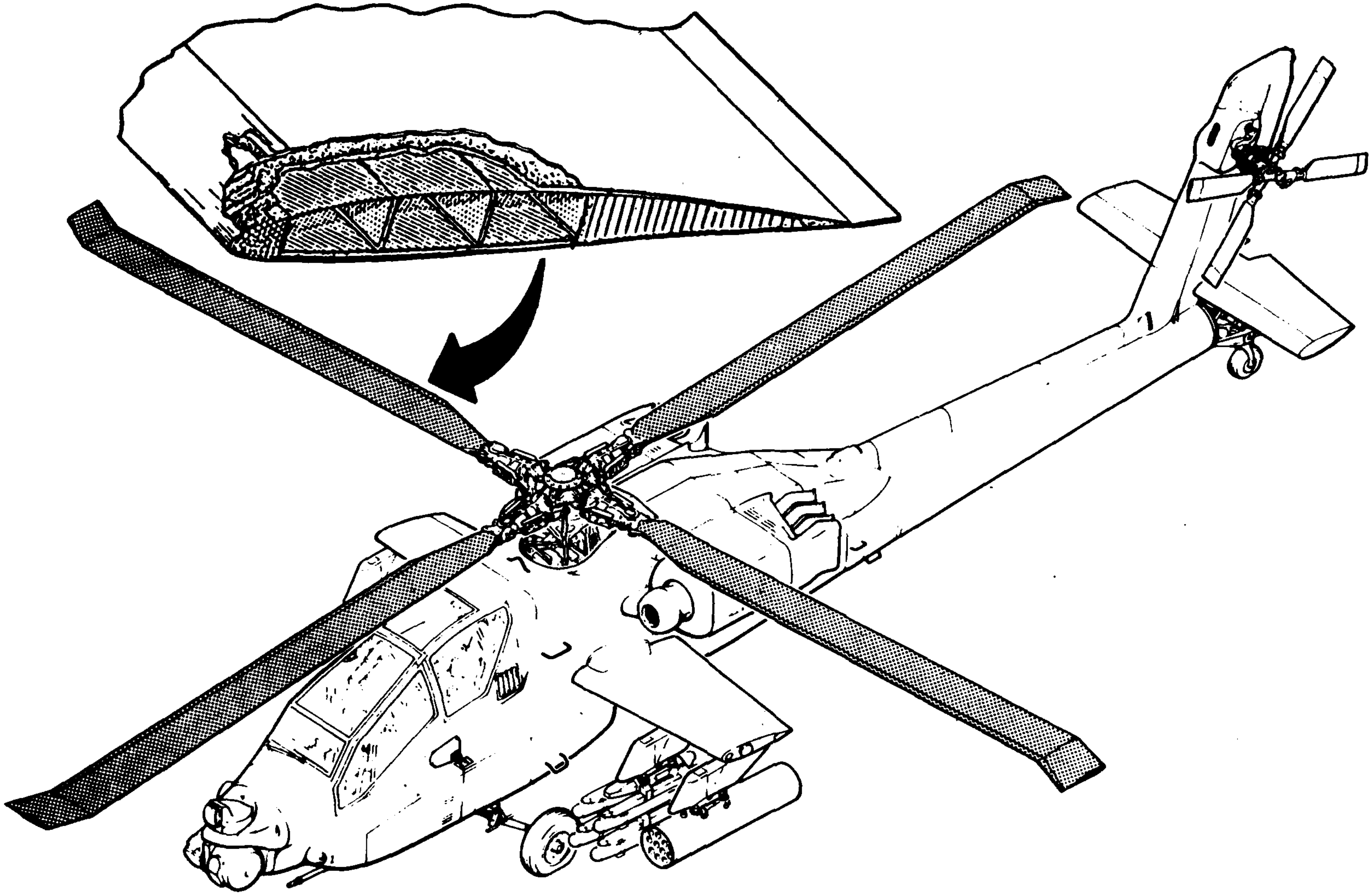

Figure 1. Composite main rotor blades for the AH-64A helicopter.

lightning tests, erosion tests in the laboratory and whirl tests on a full-scale whirlstand to prove that the fabrication process that was refined in this MM&T program provides a satisfactory main rotor blade.

An analysis of the CMRB shows that in comparison with the metal blade that it would replace in shipsets of four blades, there would be a 24-pound weight savings and a $194,300 design to unit production cost savings in 1981 dollars. These benefits make the CMRB a viable candidate for introduction into the AH-64A production program. Throughout this report direct comparisons are made between the CMRB and the metal blade that it is designed to replace so that the CMRB's improved characteristics may be judged.

The CMRB MM&T Program was initiated in four phases with a program go-ahead in February 1979.

Phase I - This phase of the program covered tool design/fabrication and initial fabrication of blades.

Phase II - Under Phase II, laboratory, whirl tower and initial flight tests were conducted.

Phase III - As a result of flight testing in Phase II modifications were incorporated into the design. Seven additional blades were fabricated, along with fatigue specimens.

Phase IIIA - Root end fatigue testing was conducted in parallel with a flight demonstration of 13.5 hours.

This report covers all work under the MM&T program except flight test. When these tests are complete, this report will be amended to include the results.

DESIGN REFINEMENT

The CMRB is planned to be a direct replacement (in shipsets) for the metal main rotor blade that was developed for the AH-64A during its prototype phase. The object of this MM&T program was to tailor the design of the blade whose geometry is shown in Figure 2 to take optimum advantage of refined composites fabrication techniques and to create a low cost blade that has:

- External geometric similarity to the metal blade
- Structural, dynamic, and performance compatibility with the metal blade
- Interchangeability (in shipsets) with the metal blade
- 4500-hour service life
- Fail safety
- Ballistic survivability (30 minutes' flight after 23mm HEI-T damages)
- Lightning protection
- Environmental protection
- Maximum utilization of filament-reinforced epoxy structure
- Minimum use of metallic components

The basic description of the AH-64A and the philosophy, structural requirements to meet its mission objectives, environments encountered during the mission, and procedures for determining specific conditions within the operational environment are described in Reference 4.

The weight, balance, inertia, and stiffness requirements were analyzed.

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[4] Anon, Design Criteria Report for the YAH-64 Advanced Attack Helicopter, Phase 2 Hughes Helicopters, Inc. Report HH 78-174, revised 15 February 1980.

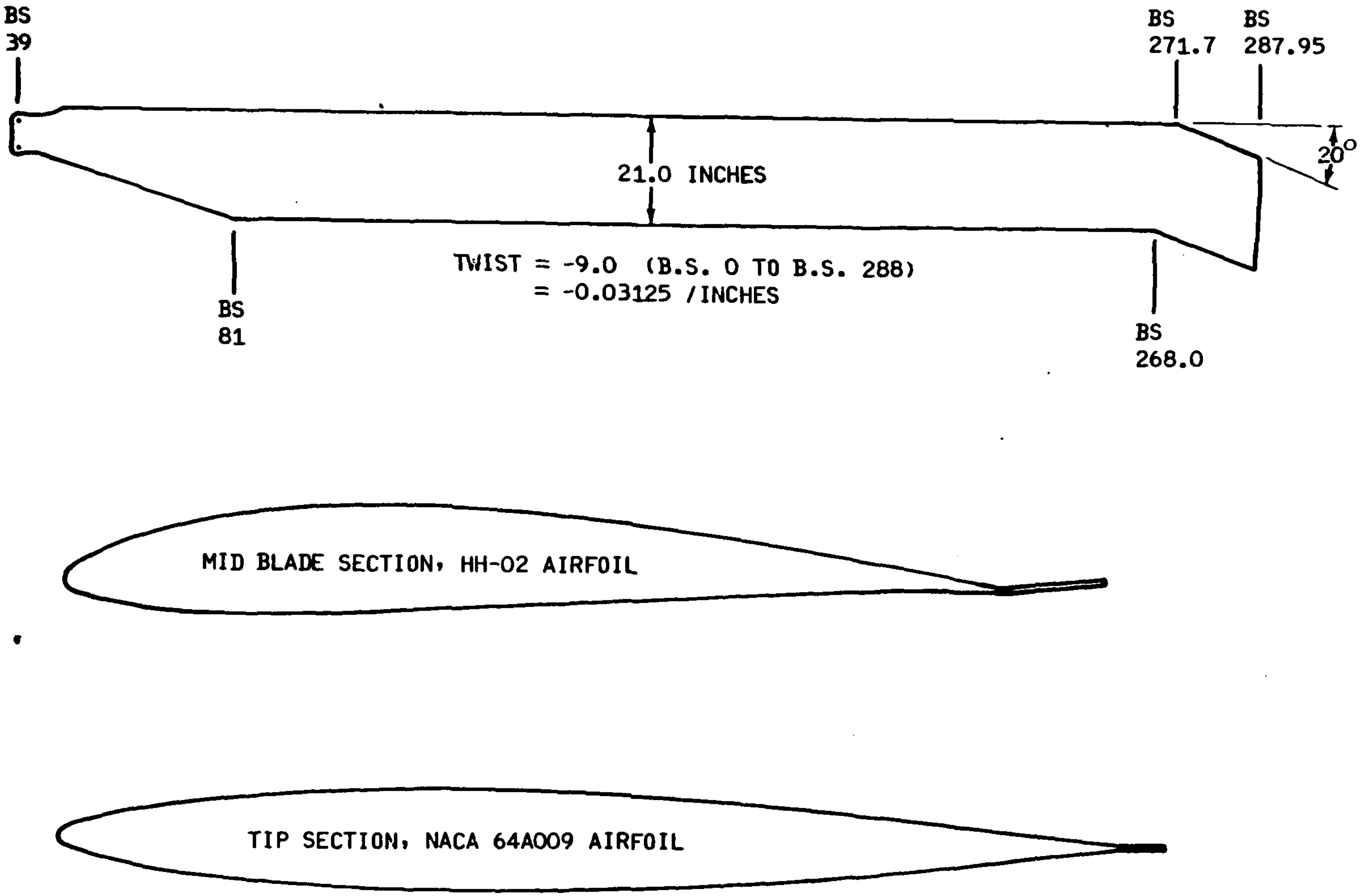


Figure 2. CMRB geometry.

The basic external loads for the CMRB are the same as those specified for the metal rotor blade in Reference 5, and in Army-approved deviations to Reference 5.

The CMRB for the AH-64A is designed according to the existing metal main rotor blade criteria, and is in accordance with the AH-64A system specification, Reference 6. Specific details of the CMRB concept are chosen to take maximum advantage of the wet filament winding fabrication experience that HHI has had in other aircraft primary structure programs for the Army.

The primary structural material for the blade is Kevlar 49 impregnated with epoxy resin. Kevlar 49 is selected for its high strength and modulus combined with light weight and superior toughness. Its tensile strength is equivalent to that of fiberglass and higher than that of graphite. Its modulus is about two times that of fiberglass. Its density is lower than both graphite and fiberglass. Its impact strength far exceeds that of graphite and is superior to fiberglass. It exhibits no degradation in water, and maintains excellent ultraviolet stability. Kevlar 49 is easily processed by wet filament winding with APCO 2434/2347 resin, a resin whose long pot life and low viscosity are well suited to the filament winding application. The excellent mechanical properties of Kevlar 49 impregnated with this resin have been proven in the MTS rotor blade program (Reference 2). Graphite/epoxy and fiberglass/epoxy are used only at strategic locations to meet specific requirements.

The CMRB structural configuration is shown in Figures 3 through 6. The CMRB has the same external contour as the AH-64A metal main rotor blade except that the tip airfoil is NACA 64A009 instead of the metal blades' NACA 64A0006, and the inboard end has a smoothly tapered buildup in thickness instead of the stepwise buildup that the metal blade's root end doublers give it. The blade attaches to the hub by two quick-acting expandable bushing bolts through the clevis-type root end fitting on the blade in a manner identical to the metal blade (Figures 3 and 6).

[5] MIL-S-8698 (ASG) Military Specification Structural Design Requirements, Helicopters, 28 February 1958.

[6] AH-64A System Specification, DRC-S-H10000B, 15 April 1982.

The structural layout uses unidirectional fibers with maximum tensile strength and modulus for the spar caps to carry high axial loads and to have high stiffness. The ±45 degree fibers with optimum shear strength and modulus are used for torsional and shear members such as spar tubes, and closures. The concept can best be described by considering three zones of the blade:

- Mid-Section – BS 84 to BS 271.7
- Root Section – Inboard end to blade Station (BS) 84
- Tip Section – BS 271.7 to outboard tip

Refer to Figure 6.

MID SECTION

Two rotor blade development programs that HHI has conducted for the Army (AH-64 blade and MTS blade) have demonstrated that to have survivability against the 23mm HEI-T threat, the primary structure must be distributed over at least 50 percent of the chord and further, must have a minimum extent of at least 10 inches. The CMRB uses this concept as Figures 4 and 6 show. Referring to Figure 4, everything forward of the front edge of the honeycomb core is primary structure. The structure consists of a top and a bottom unidirectional spar cap for centrifugal strength and flapwise bending strength and stiffness, ±45-degree spar tubes and inner and outer skin for torsion strength and stiffness, and spanwise steel rods in the leading edge weight for chordwise bending strength and stiffness, while its trailing unidirectional longitudinal filaments (longo) acts with the steel rods in the nose for chordwise bending strength and stiffness. An electro-thermal deicer blanket covered by a stainless steel erosion protection strip and polyurethane anti-erosion material is bonded to the front of the blade. Narrow strips of aluminum screenwire bonded into the top and bottom skin near the trailing edge conduct lightning energy from the blade tip of the rotor hub. The trailing edge tab is mounted on a metallic hinge that may be bent to facilitate blade tracking.

The outer skin is one continuous piece of 0.030 inch thick Kevlar 49, that provides a major portion of the blade torsional stiffness and shear tie for the spar caps and the trailing edge longo. For torsional strength inboard, the skin is reinforced with doublers. The inner skin is a Thornel 300 graphite fabric that covers the main spar section throughout the length of the blade for additional torsional strength.

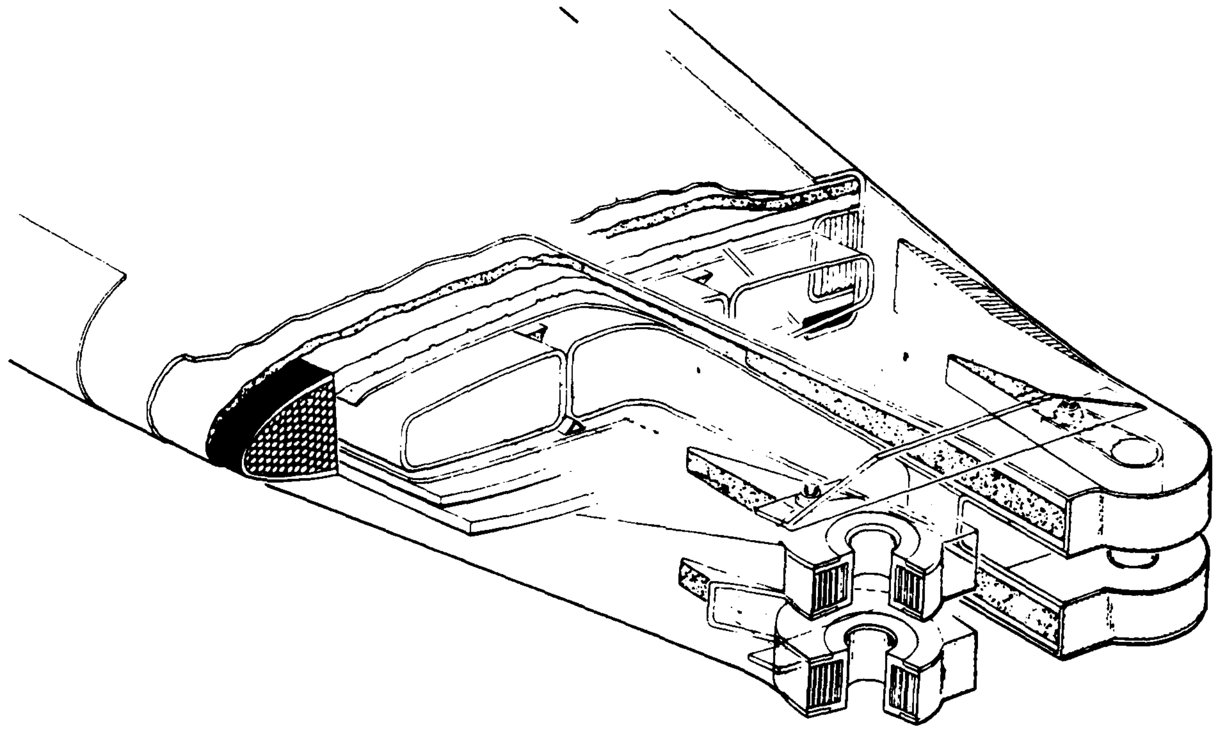


Figure 3. Composite main rotor blade AH-64A root end configuration.

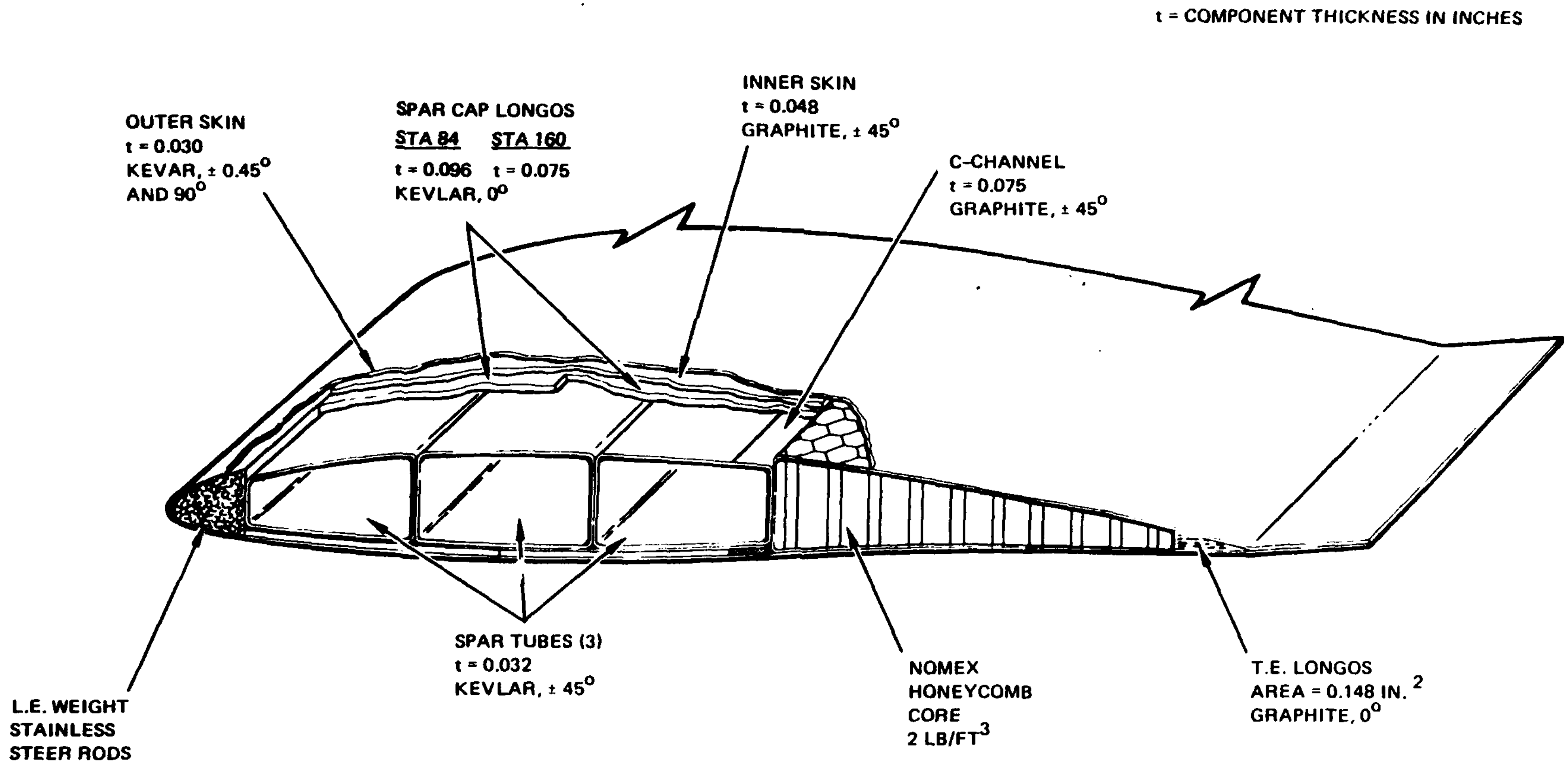


Figure 4. CMRB construction.

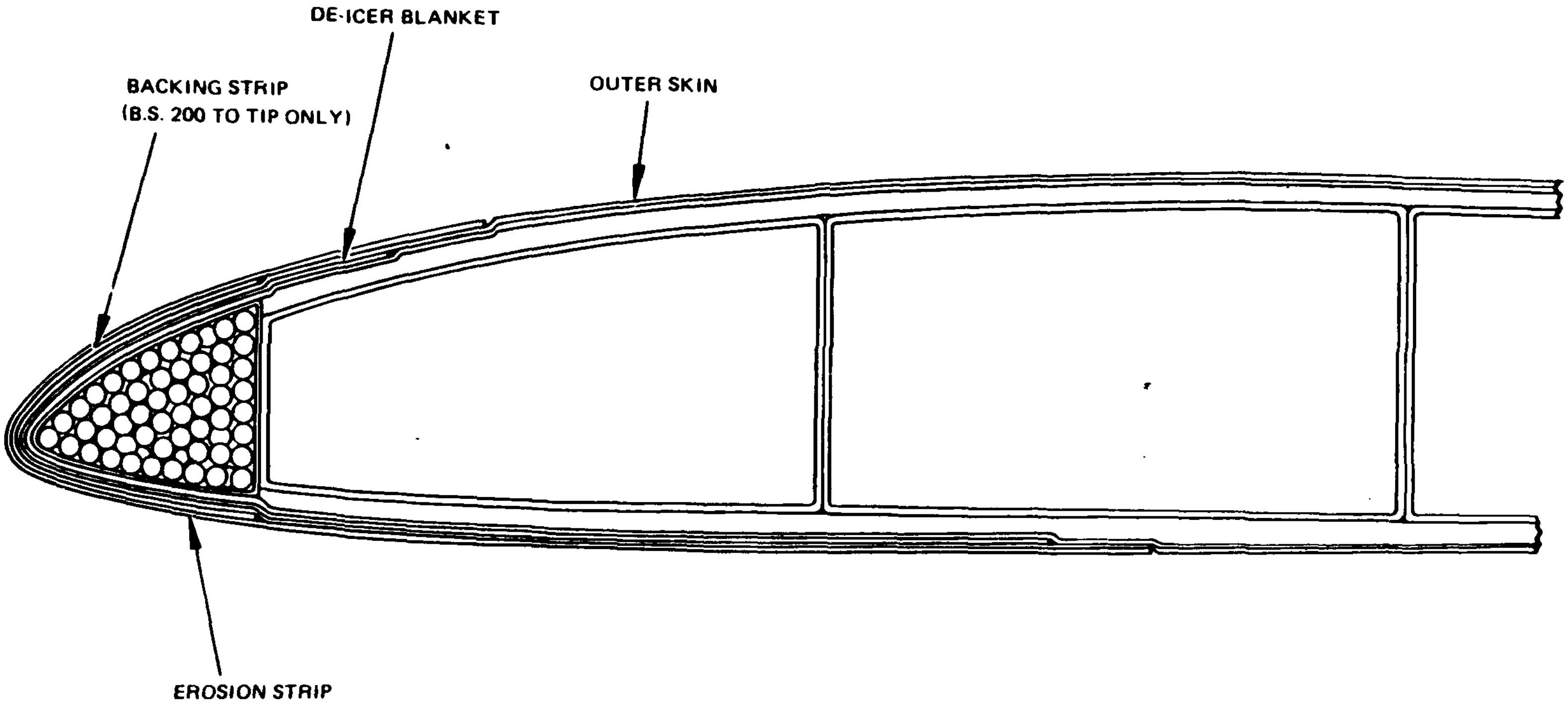
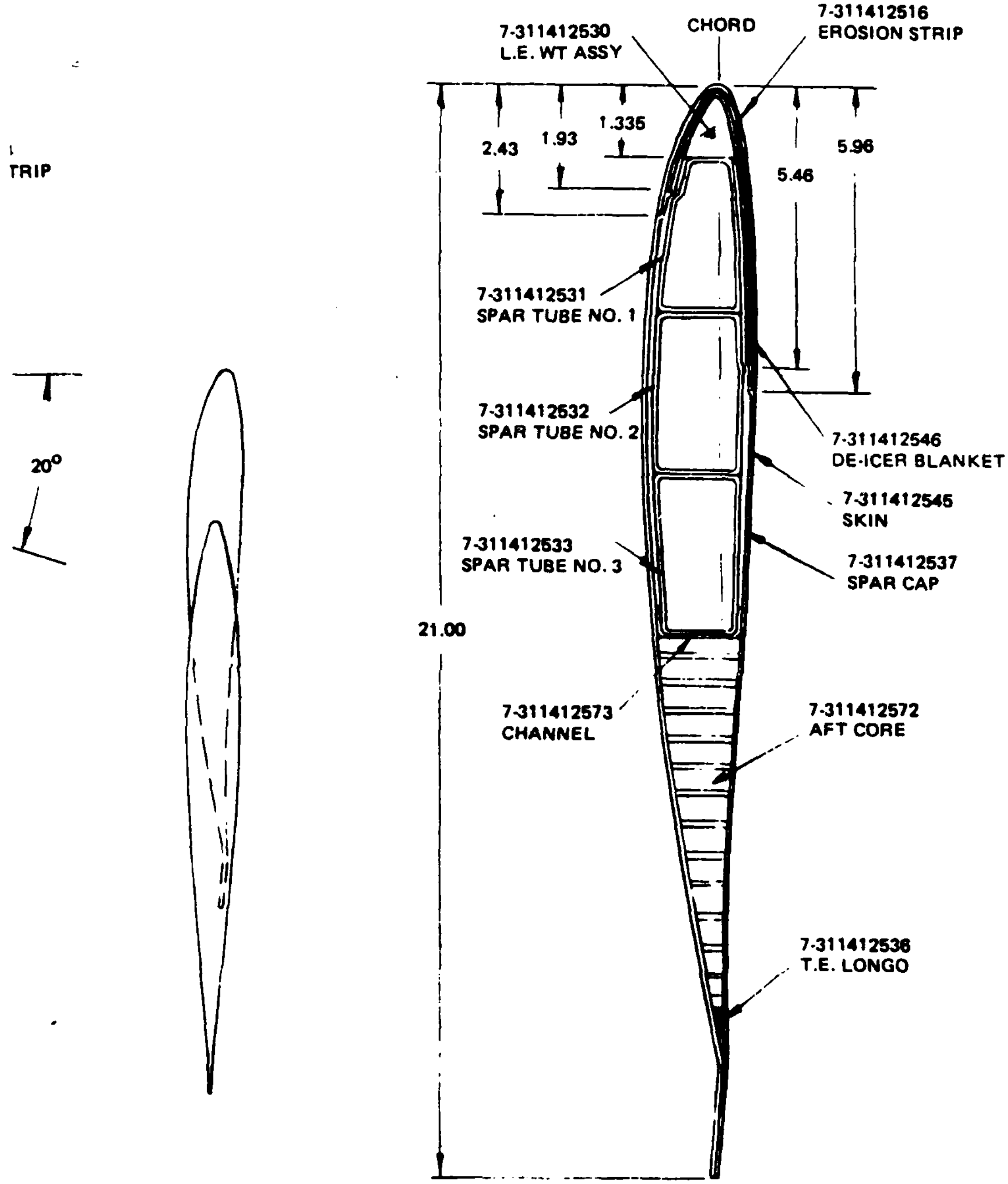


Figure 5. Leading edge protection.



SECTION A-A

Figure 6. Composite main rotor blade for AH-64A.

The leading edge balance weight consists of sixty-eight pieces of 3/32 inch diameter, 316 stainless steel rods embedded in milled fiber/epoxy and over-wrapped with one ply of style 1581 E-glass fabric. The multiple rod molded construction eliminates complicated machining since the small diameter rods are flexible and easily conform to the twisted contour of the leading edge weight mold. The multiple rod construction minimizes crack propagation in case of local damage. The leading edge balance weight extends from BS 49 to BS 271, and provides chordwise balance as well as a portion of chordwise stiffness.

An 0.020 stainless steel backing strip is bonded to the blade leading edge beneath the erosion strip outboard of BS 201 to the blade tip end. The backing strip is segmented into three separate butted sections to avoid contributing to blade stiffness properties. The backing strip provides blade leading edge protection to the high wear rate region in the event of premature damage to the polyurethane that covers the entire span to protect it from erosion.

Each of the upper and lower spar caps is made up of two longo packs of unidirectional Kevlar 49 fibers. The longo pack is continuous from the blade tip inboard around a 17-4 PH steel bushing where the blade attaches to the hub and back outboard to the tip. Outboard of BS 84, the longo pack cross sectional area tapers from 0.442 square inch to 0.345 square inch at station 160 and then remains constant to the tip.

The three spar tubes are individually wound from Kevlar 49. Their wall thickness is 0.032 inch. The aft side of the aft tube is reinforced with a 0.075 inch thick graphite C-channel to carry the shear load from top to bottom of the blade. The spar tubes contribute a small amount to the torsional stiffness, but more importantly, serve as alternate load paths in case of ballistic damage.

The aft airfoil blade section is a sandwich construction with Nomex honeycomb core between the upper and lower skins. The trailing edge longo is fabricated from unidirectional Thornel 300 graphite fibers.

Two tip weights are placed in the outboard end of the mid-section, just inboard of the swept tip with one on each side of the 25 percent chord line. See Figure 6. This arrangement allows balancing of the blade in both the spanwise and chordwise directions. A stainless steel tip weight is wound into the outboard end of the forward spar tube, and an aluminum tip weight into the aft spar tube. Each of these weights has a necked down area at the inboard end into which the fibers of the tube are wound for excellent mechanical retention. The weights are also directly bonded onto the spar caps. A cavity in the outboard end of each weight accepts adjustable tungsten balance weights that are secured in place by a 3/8-inch diameter bolt. A metallic cover that fairs to the blade's lower surface seals the opening of each cavity.

ROOT SECTION

This is the strong section through which the blade attachment is made to the hub. Figure 4 illustrates this region. The main feature is the double clevis for the attachment bolts. This is made up of four spool-shaped 17-4 PH stainless steel bushings that accept the mounting bolts and around which are wound the spar cap longos that run the length of the blade. By looping the longo filament around the bushings, a secure mechanical attachment is provided. In fact, each of these four longo packs, individually, is capable of retaining the centrifugal force of the entire blade.

Inboard of BS 84 the longo packs build up uniformly with additional unidirectional Kevlar 49 filaments to serve the same purpose as doublers on a metal blade. Skin doublers made of ±45 degree Kevlar build up the torsional strength of the blade in this same region.

A number of cavities near the root end of the blade, such as the triangular regions between the longo packs around the bushings, the space between bushings, and the ends of the spar tubes are filled with syntactic foam (glass microballoons and epoxy). A Kevlar/graphite/epoxy end cap is bonded on to close off the inboard end of the blade.

TIP SECTION

The primary structure (main spar section) of the swept tip region is a structural continuation of the main portion of the blade. The forward section, outboard of the spar tubes, at the swept tip region is filled with a premolded longo, chopped fiber, and foam core to ensure structural rigidity. All these elements are co-cured with the basic blade. The aft section of the swept tip combined with the tip cap forms the tip closure. This is a sandwich construction with 0.015 inch thick fiberglass skins and Nomex honeycomb sandwich core. The tip closure is attached by means of a secondary bonding operation. Syntactic foam is used to fill miscellaneous cavities.

BLADE MODIFICATION

Two major problems, one discovered in root end fatigue tests and the other in the whirltower tests, were corrected by modifying the design concept.

The whirltower tests showed an unacceptable softness in the aft portion of the blade that permitted camber changes and led to out-of-tract conditions and high pitch link loads. Figure 7 shows the cross section of the blade as originally designed with the internal structure of the aft portion being a series of tubes. The fix used on the whirltower consisted of adding external strips of graphite to the trailing edge skin as Figure 8 indicates. The final design refinement, as shown in Figure 4, removed the support tubes from the aft part of the blade, replaced them with a Nomex honeycomb filler, added graphite inner skins, and a graphite channel — all to increase torsional stiffness.

The blade root fatigue tests showed that the longo filaments lacked proper support where they loop around the root-end bushings, and could not carry the loads reliably. The original design of the bushing had only one flange as Figure 9 shows. Under load, the filaments tended to bulge off of the end of the bushing away from the flange. There was never any danger of the blade actually coming off the hub, but the bushing-to-longo-connection could become unacceptably loose. Giving the bushing a second flange like that shown in Figure 10 solved the longo restraint problem and at the same time allowed 10 percent more longo filaments to be placed around the bushing for increased strength. Simultaneously with the bushing redesign, a graphite clevis plate was inserted top and bottom in the blade root to give additional support to the bushings.

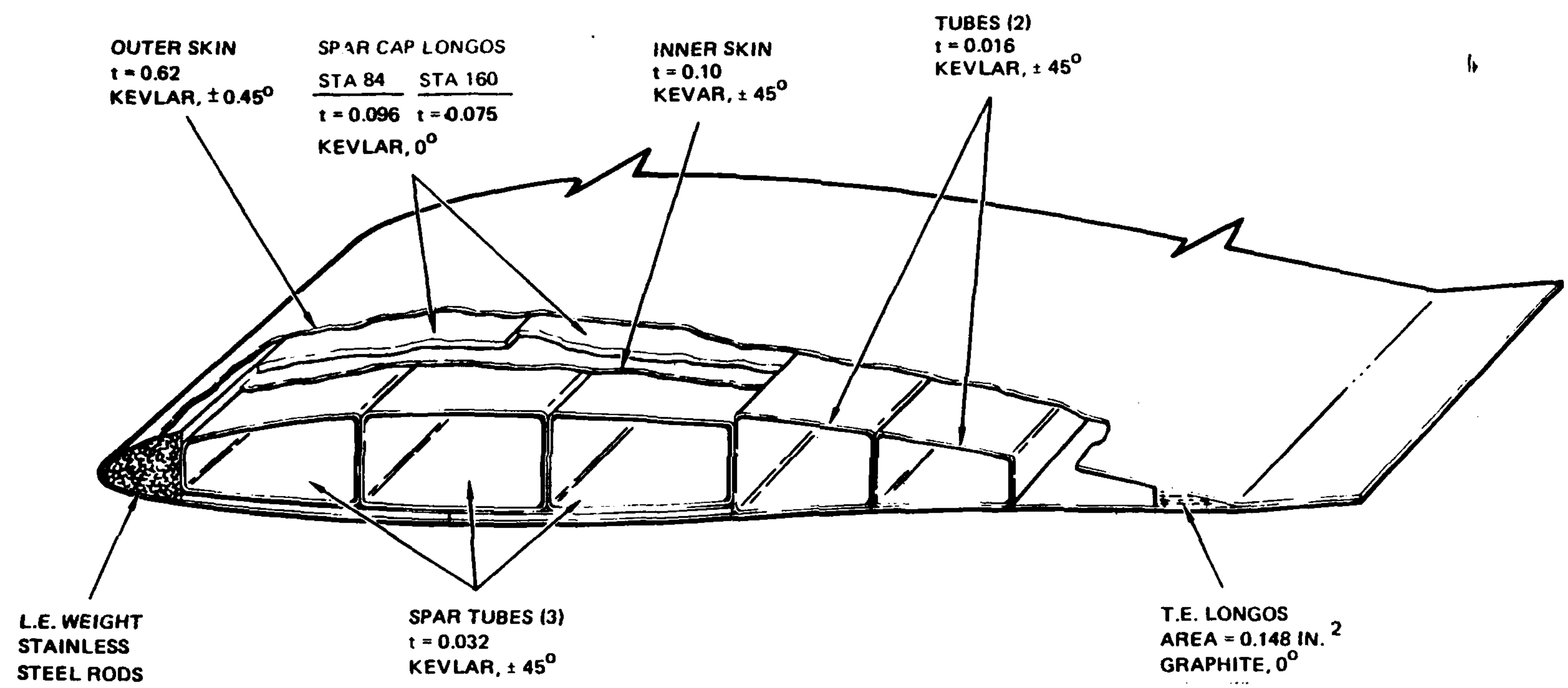


Figure 7. CMRB original construction.

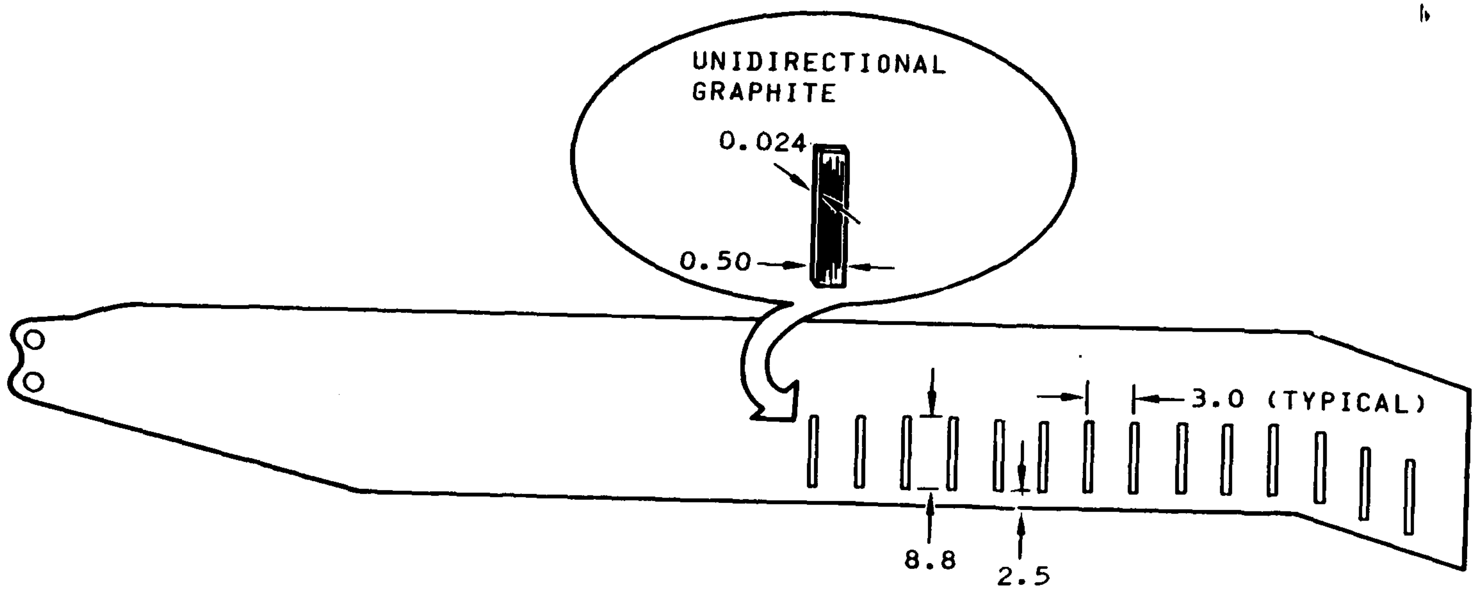


Figure 8. Aft blade stiffening (whirltower Mod 2).

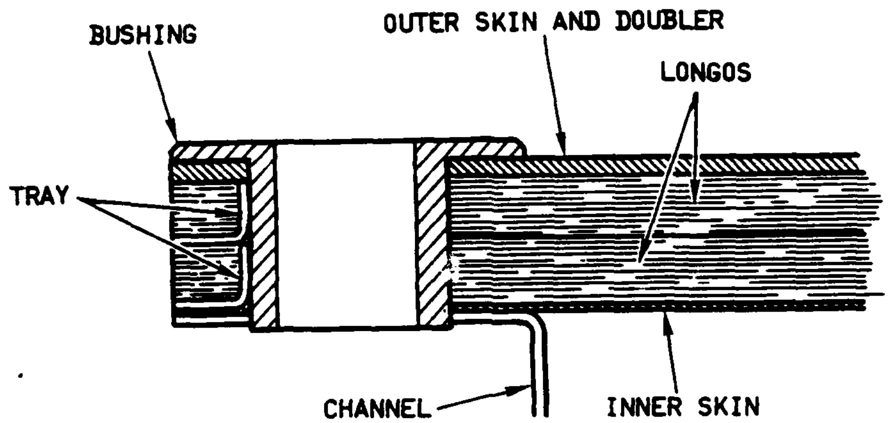


Figure 9. Root end bushing/longo detail (original).

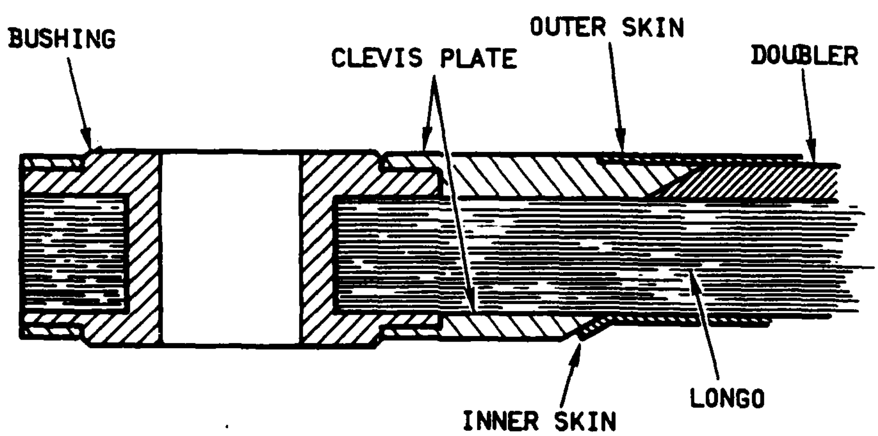


Figure 10. Root end bushing/longo detail (modified).

MANUFACTURING TECHNOLOGY ESTABLISHMENT

Work that HHI had done previously in the field of advanced composites primary structures was mainly in the field of the wet filament winding (WFW) cocure process. The CMRB MM&T program was structured to continue the use of this process to the greatest extent possible, and to refine it for the special requirements of the rotor blade.

The WFW process for fabricating cylindrical components is summarized in Figure 11. This figure shows how bands of rovings are laid onto a rotating mandrel along geodesic paths until the entire surface of the mandrel is covered with a layer of filaments oriented in a ± angle pattern. As many layers as required may be superimposed. This process can lay filaments onto a mandrel at any angle between approximately ±5 degrees and 90 degrees relative to the axis about which the mandrel rotates. Because the band of rovings follows a geodesic path to avoid slipping, the orientation is constant ± angle from end to end on a cylindrical mandrel, but it is a variable angle from end to end if the mandrel is conical (small ± angle at the large end to large ± angle at the small end). Each end of the mandrel has a suitably shaped dome for securing the filaments and guiding them smoothly as they turn around to make the reverse pass along the mandrel. It has been demonstrated that the mandrel need not have a circular cross section - rectangular and triangular cross sections are readily wound.

The band of wet rovings is created by passing a number of dry filament rovings (approximately 12 in number) through a resin impregnator such as the one shown in Figure 12. It meters resin into the filaments to achieve a fixed fiber volume ratio. All of the filaments may be alike, say graphite, or they may alternate, say graphite and Kevlar, to form a hybrid composite. The delivery eye, whose travel along the mandrel is geared to the rotation of the mandrel, guides the band of wet filaments onto the mandrel at the desired angle.

Skins of ±45° Kevlar and a 90° hoop wind are fabricated in this manner around a special skin winding mandrel and then slit longitudinally. The ±45° Kevlar wraps are chosen for high torsional stiffness and strength while the 90° wrap provides ballistic strength. Other parts, wuch as the spar tubes, are then filament wound, using a pre-expanded styrofoam mandrel.

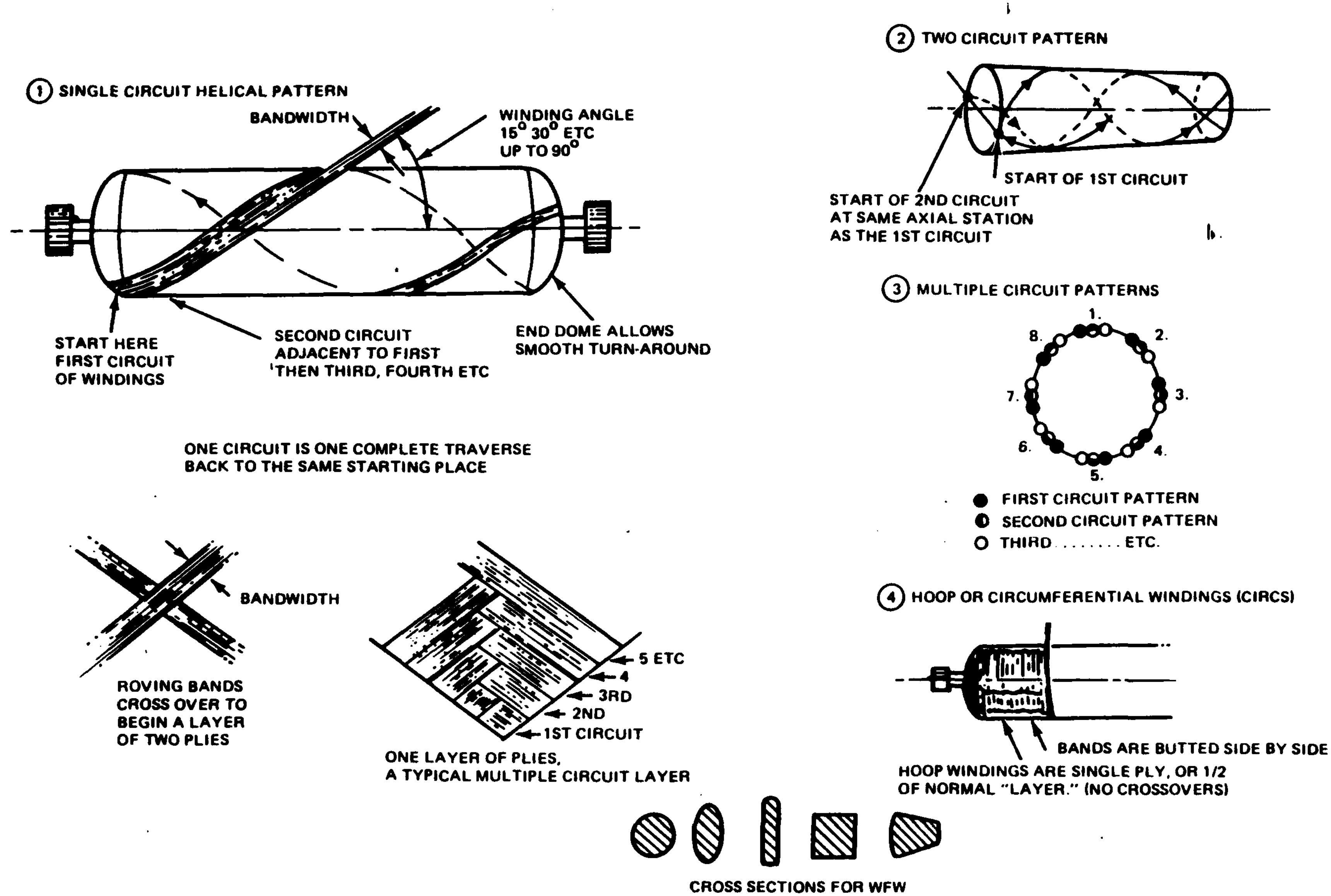


Figure 11. Tubular element filament winding process.

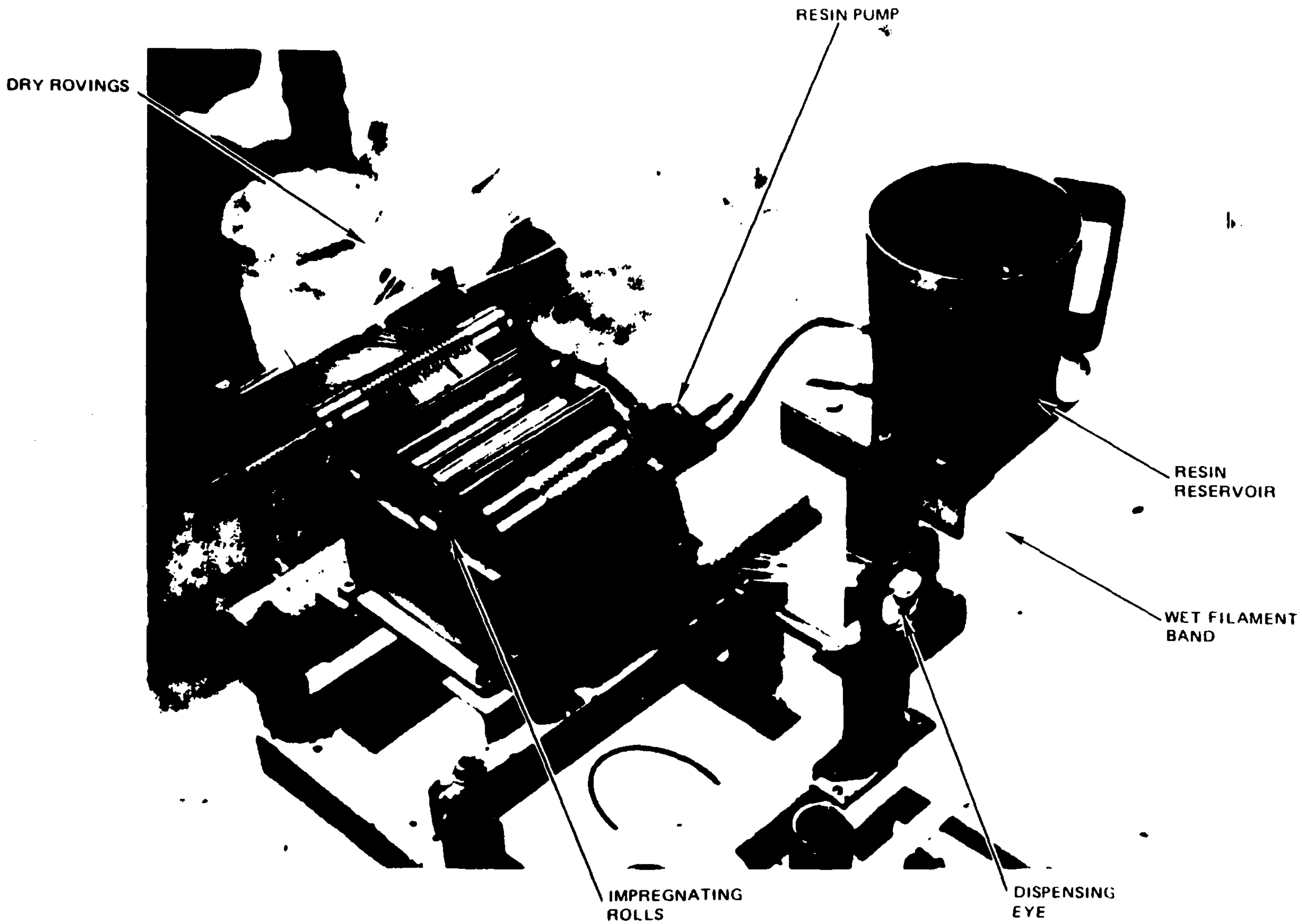


Figure 12. Resin impregnator.

This mandrel is preformed by compression to shape in closed molds. Down the center of each mandrel runs steel tubing, with slots along the length for internal air pressurization. It is placed in a nylon bag and over that goes a tedlar bag. The bags are pressurized to check for leaks, and then placed on the winding machine to be wound at ±45 degree angle using Kevlar 49 with epoxy/resin system to provide high torsional stiffness and strength.

A special case of end dome fitting can make the end fitting a permanent part of the filament wound tube. An example of this is the weight attached to the number 1 and 3 spar tubes in the CMRB, wherein the weight has the same cross sectional shape as the tube and has a groove into which the filaments are wound for a secure mechanical connection. Figure 13 illustrates this concept.

Longo winding is another WFW process in which the wet filament dispenser runs around a "racetrack" path and lays down bands of wet unidirectional filaments around a pin at each end of the table as indicated in Figure 14. Auxiliary pins near each end of the table guide the filaments to provide the length needed for spreading them uniformly.

The four spar cap longos (two top and two bottom) and the trailing edge longo are made on the wet filament winding racetrack machine. In the case of the trailing edge, the longo is wound around end pins that are later discarded. In the case of the spar cap longos, a metal bushing takes the place of the pin at one end of the winding table. The bushing remains with the longo and becomes part of the final blade assembly. The guide pins that spread the filaments are removed from the winding table and the longo is rolled flat and uniform by manually operated grooved rollers.

After being wound, the spar caps are then placed in a subassembly fixture. The fixture consists of two spar caps which are tensioned and then go through a debulking process. An aluminum tool is forced around the bushing end to compact the rovings, and then a root-end dam is positioned around the spar cap assembly. The spar cap is then trimmed to create a tapered assembly having more rovings around the root end, and then tapering to a constant dimension.

The components are then held in a freezer which is maintained at 0°F. The freezer allows us to extend the working time to two weeks. At room temperature, the working time is 24 hours, while at 40°F it is 72 hours.

Graphite (Thornel 300) is chosen for the trailing edge longo for both stiffness and strength so that proper chordwise dynamic tuning is provided. It is "B-staged" in a fiberglass mold at room temperature.

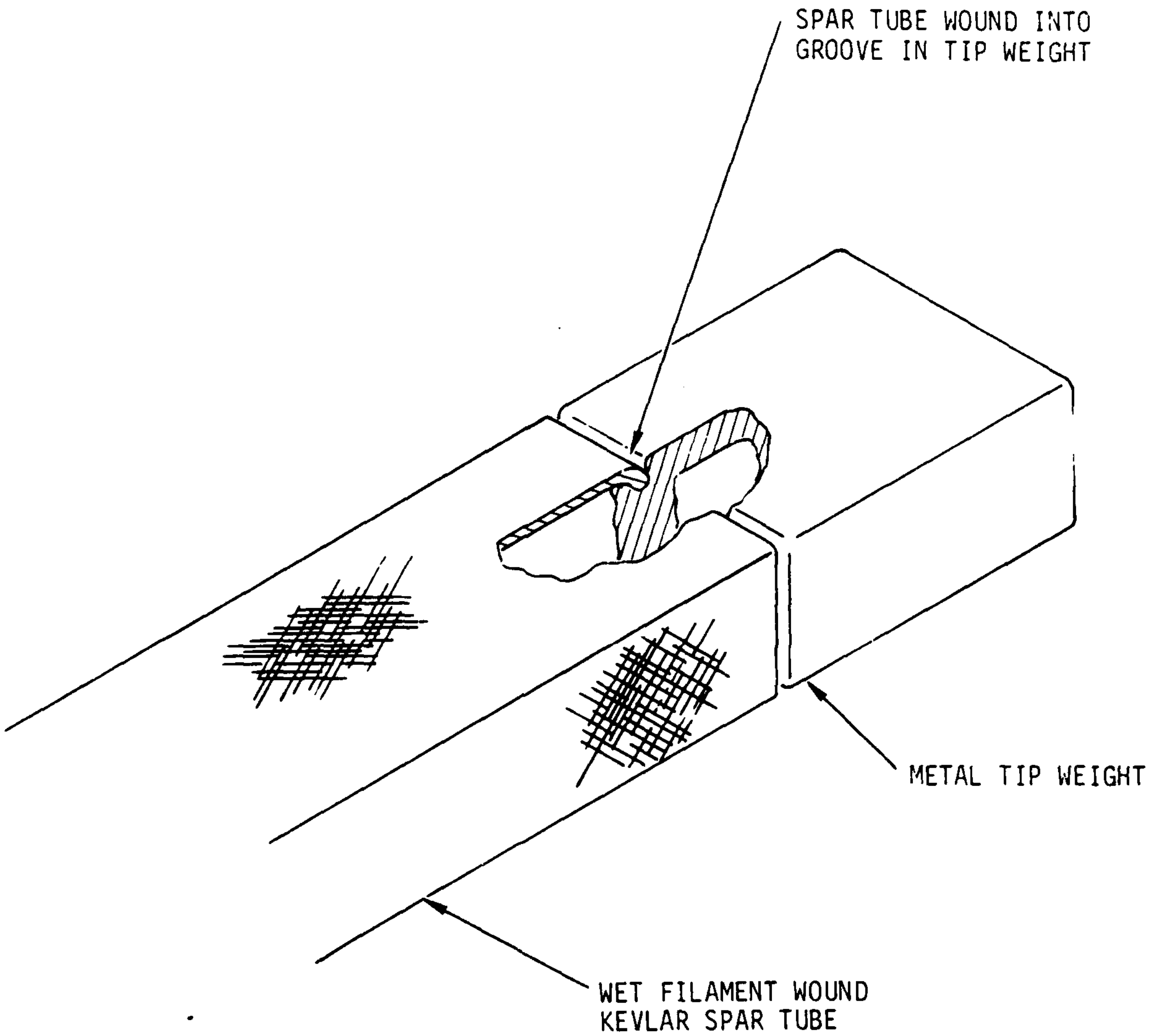


Figure 13. Spar tube/tip weight connection.

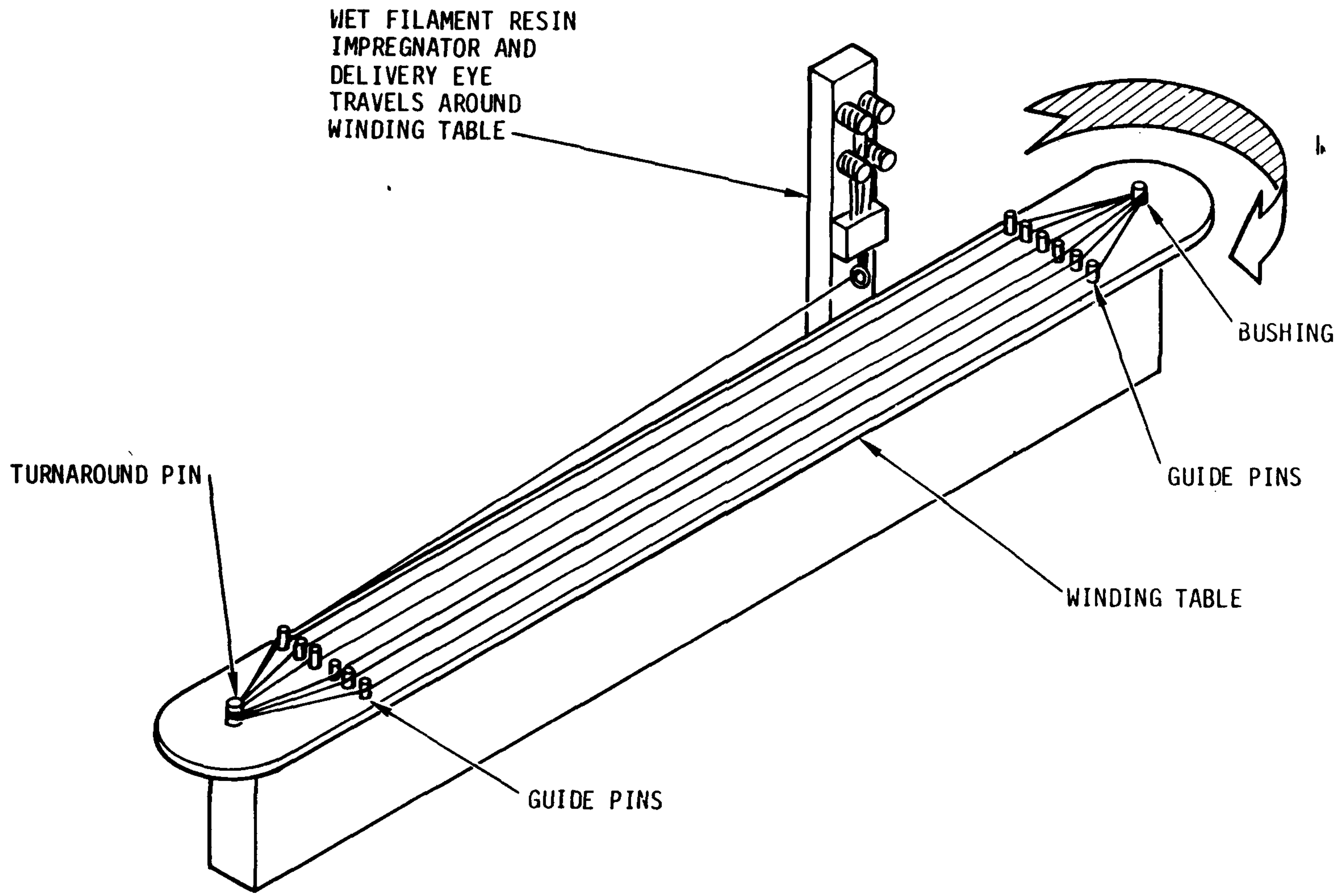


Figure 14. Longo winding.

Kevlar 49 is utilized for high strength in the spar caps. The specially developed steel double flanged spool provides fatigue strength of the lugs of the blade.

Premolded parts that go into the final cocure assembly include:

- C-channel laid up in a fiberglass mold using ±45 degree graphite fabric manually impregnated with resin and cured at 300°F in an oven.

- Leading edge weight made up of steel rods and milled fiber/epoxy laid up manually in a fiberglass mold shaped to fit the leading edge of the blade, and cured at room temperature.

- Root end dams, made from glass microballoons/epoxy, are cast in fiberglass molds and cured at room temperature.

- Tip core foam is molded from foam-in-place polyurethane in a fiberglass mold and is cured at 300°F.

- Tip core longos are wound from Kevlar/epoxy filaments, are combined with the tip core foam in a fiberglass mold, and are cured at 160°F.

- Outboard closure includes top and bottom "B-staged" fiberglass skins, film adhesive, and Nomex honeycomb core. They are assembled in a fiberglass mold and cured at 225°F.

- Outboard cap is made from wet fiberglass fabric that is formed on an aluminum mold and cured in a vacuum bag at 270°F.

- Inboard closure is made from wet Kevlar fabric and wet graphite fabric that is formed on a fiberglass mold and cured in a vacuum bag at 300°F.

Inner and outer skin doublers of ±45° Kevlar and ±45° graphite are hand impregnated and cut to size.

Honeycomb core is sawed to shape and finally sanded to tolerance for the afterbody. Two pound per cubic foot nomex was chosen for airfoil stabilization and to reduce lightning vulnerability.

The major assembly of blade takes place in a closed-cavity, pressure-balanced, self-heated mold in a single cocure operation. This type of mold was pioneered by HHI in the MTS Blade Program (Reference 2). The mold and heating systems are shown schematically in Figure 15 and in the photographs of Figures 16 and 17.

Figure 16 shows the end of the mold that hot water/steam enters and from which it returns to the boiler room for reheat. The manifolds with their fire hoses attached are visible, and the multiple hinged rods that tie the top and bottom of the mold together may be seen along the sides. Figure 17 shows the opposite end of the mold with the air lines that pressurize the spar tubes protruding. The "pressure balance" designation comes from the relatively thin mold blocks that are forced closed by a uniform pressure from the fire hoses, while pressure is applied to spar tubes inside the blade to force the skin and spars out against the mold surface. The honeycomb in the aft portion of the blade is made a little oversize and is crushed when the mold closes to provide pressure to the skin-to-honeycomb bond area.

The MM&T program refined the process by which the CMRB is fabricated. In general terms, the process is as described below. More details are given in the Process Specification.

- Clean and prepare the molds.

- Mold the precured components described above, seal them in plastic bags to protect them from the environment, and store them until needed in final assembly.

- Prepare the inner skin and doublers, and store them in sealed plastic bags in a refrigerator.

- Wet filament wind the three spar tubes (see Figure 18) and store them in sealed plastic bags in a refrigerator.

- Wet filament wind the five longo components (four spar longos and trailing edge longo), as shown in Figure 19, trim their doubler filaments, roll them flat and uniform, and store them in sealed plastic bags in a refrigerator.

- Wet filament wind the skin on a machine like the one in Figure 18, cut it loose from its mandrel, lay half of it in the bottom half of the mold (remainder remains draped on its mandrel).

- The inner skin is then placed onto the outer skin.

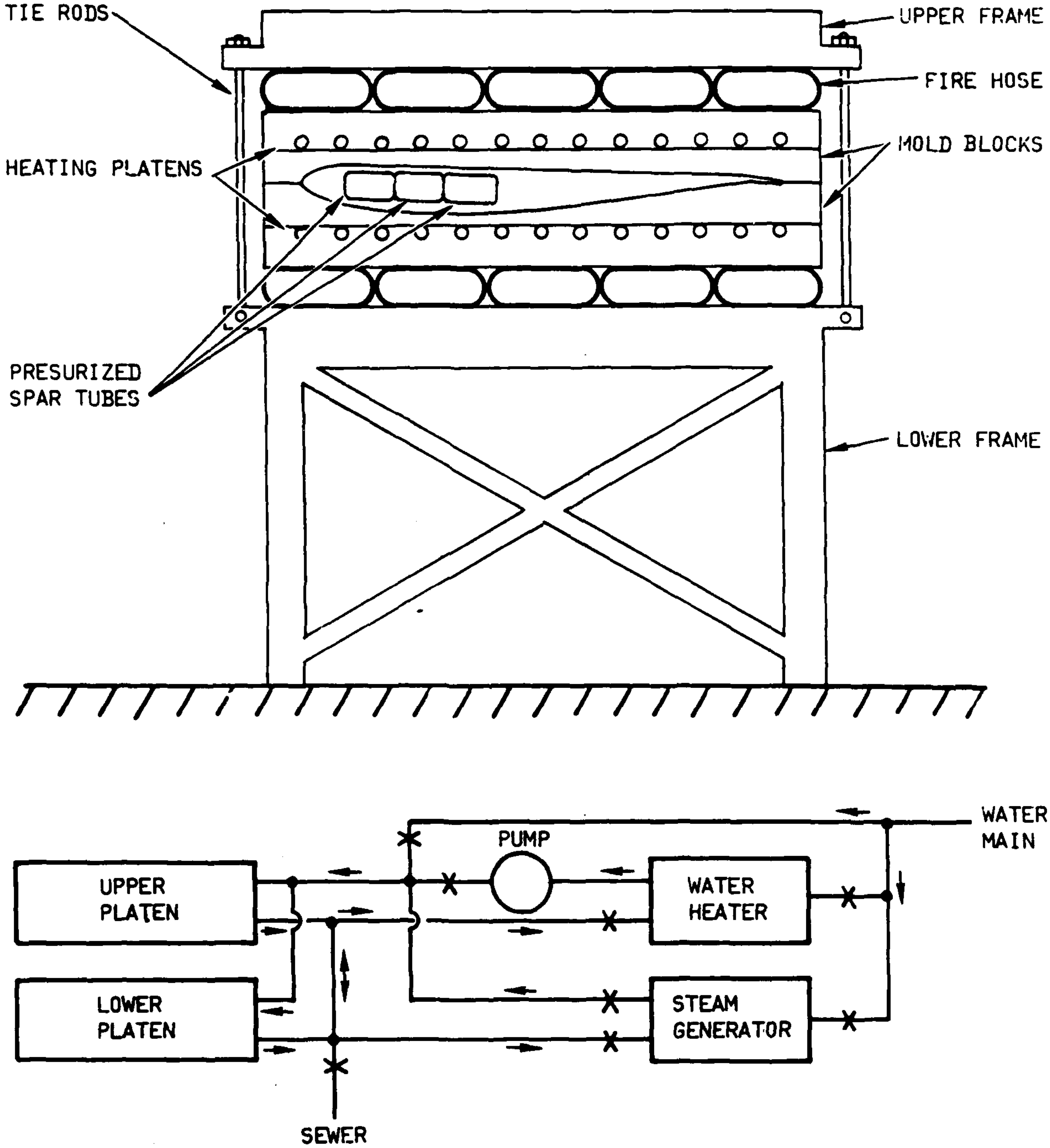


Figure 15. Pressure-balance, self-heated mold schematic.

Figure 16. Pressure – balanced mold for CMRB.

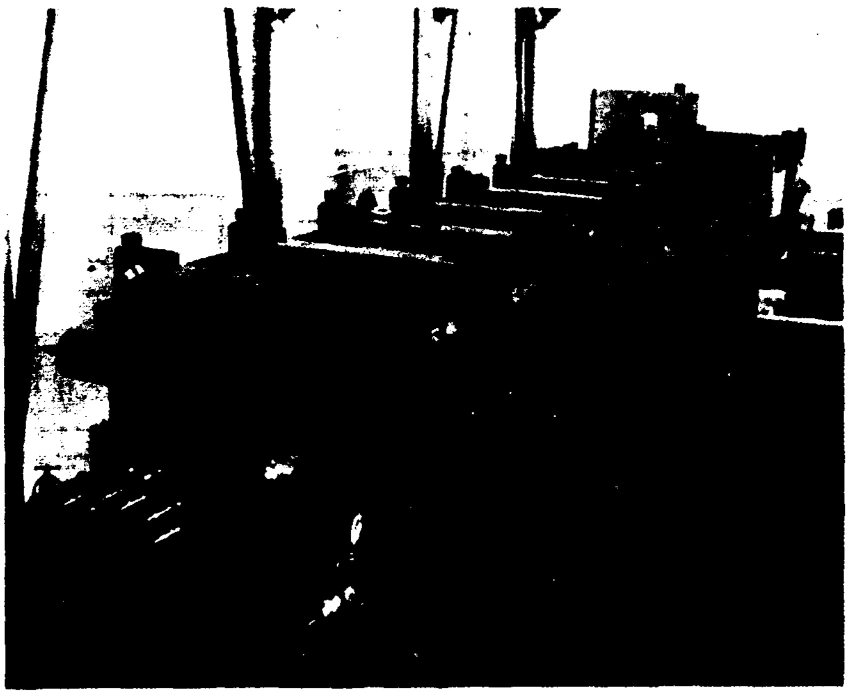


Figure 17. Pressure – balanced mold for CMRB.

Figure 18. CMRB spar tube wet filament winding.

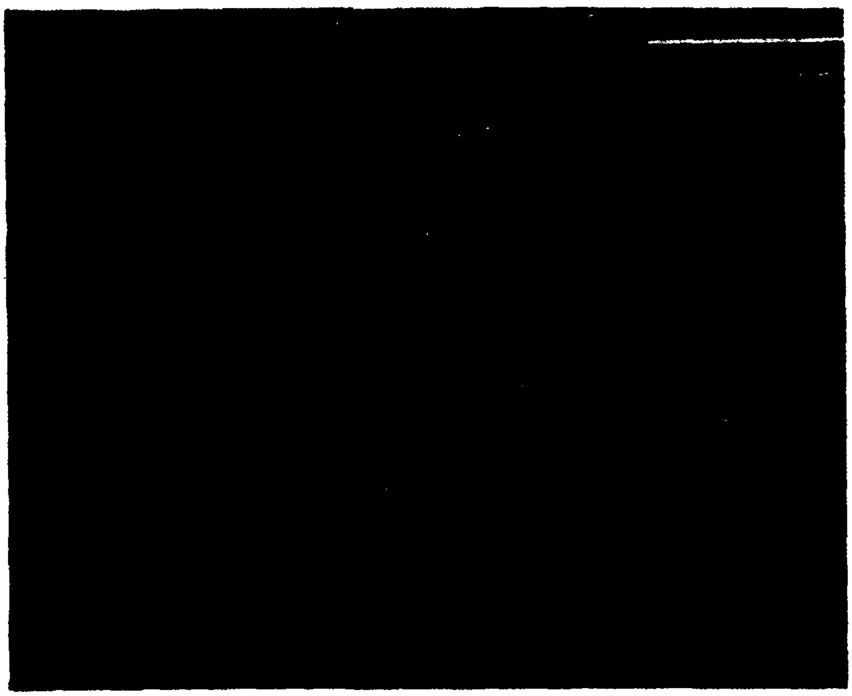


Figure 19. CMRB spar longo wet filament winding.

- The spar cap subassembly is then placed in the blade mold. All the rovings are rolled out smooth. The leading edge weight is installed and tied to the front of the mold. The spar tubes are next laid in position followed by the precured graphite C-channel.

- The location tool is then installed, assuring proper positioning of the forward section of the blade assembly. The second spar cap assembly is added, the tool is then removed, and the inner skin is laid over the top of the second spar cap assembly.

- The Nomex honeycomb aft section is installed.

- The trailing edge longo is assembled into position over pins in the 120 weave positioning ply.

- Root-end doublers are added and the outer skin is laid over the top of the blade. The top half of the mold is then installed, and the upper portion of the press is installed and secured. The blade mold is a two-piece numerically controlled machined aluminum tool with a hot water/steam heated platen on each side of the mold. Pressure is generated through the use of two-inch dia fire hoses in the press, allowing the mold and platens to float during the cure cycle. Pressure is applied to the press, top and bottom. The three spar tubes are then pressurized. First, hot water, and then steam are applied to the mold for the cure cycle.

After cure, the blade is removed from the press. The three steel tubes are then removed from the spar tube assemblies. The blade is then trimmed, followed by a series of secondary bonding operations. The electrical deicer blanket, stainless steel backup strips, polyurethane erosion strip, root end closure, and trim tabs are installed. The blades are then painted, weighted, and balanced.

MATERIAL SELECTION

HHI uses Applied Plastics Corporation's (APCO) epoxy resins and hardeners as the matrix material for the CMRB:

- APCO 2434/2347 Resin System - low viscosity and long pot life for wet filament winding applications. Resin cures at 300°F with a high degree of resultant cross link density. ($T_9 \cong 260°F$.) Extremely chemical and solvent resistant following cure. Excellent shear properties when used in conjunction with Kevlar reinforcements. (HMS 16-1115 Type I, Class 1.)

- APCO 2434/2340 Resin System - low viscosity, room temperature setting - final curing compatible with 2434/2347 resin. Similar mechanical properties to 2434/2347. (HMS 1115 Type I, Class 3.)

- APCO 2434/2180 Resin System - low viscosity, room temperature set and cure. Capable of elevated temperature cure cycles - compatible with above referenced resin systems. (HMS 16-1115 Type II.)

The 300°F cure hardener, 2347, is used for all filament winding of major structural elements. It is formulated to have a 24-hour pot life at room temperature, but this time can be extended to 72 hours if stored at temperatures below 40°F, and to two weeks if stored at 0°F.

Evaluation tests have shown that the APCO 2434/2347 resin system has optimum properties when cured according to the time/temperature cycle shown in Figure 20. This cycle raises the glass transition temperature above the range of normal operating temperatures for strength at elevated temperatures, and for minimized micro-cracking. The 2180 and 2340 hardeners are used for certain subcomponents.

- Kevlar Reinforcements, rovings and woven cloths - good physical characteristics including tensile, tensile modulus and ballisitc. (HMS 16-1164.)

- Graphite Reinforcements, rovings and woven, cloth - used primarily in areas where increased stiffness is required. Example: T/E long, C-channel and inner skin. (HMS 16-1163.)

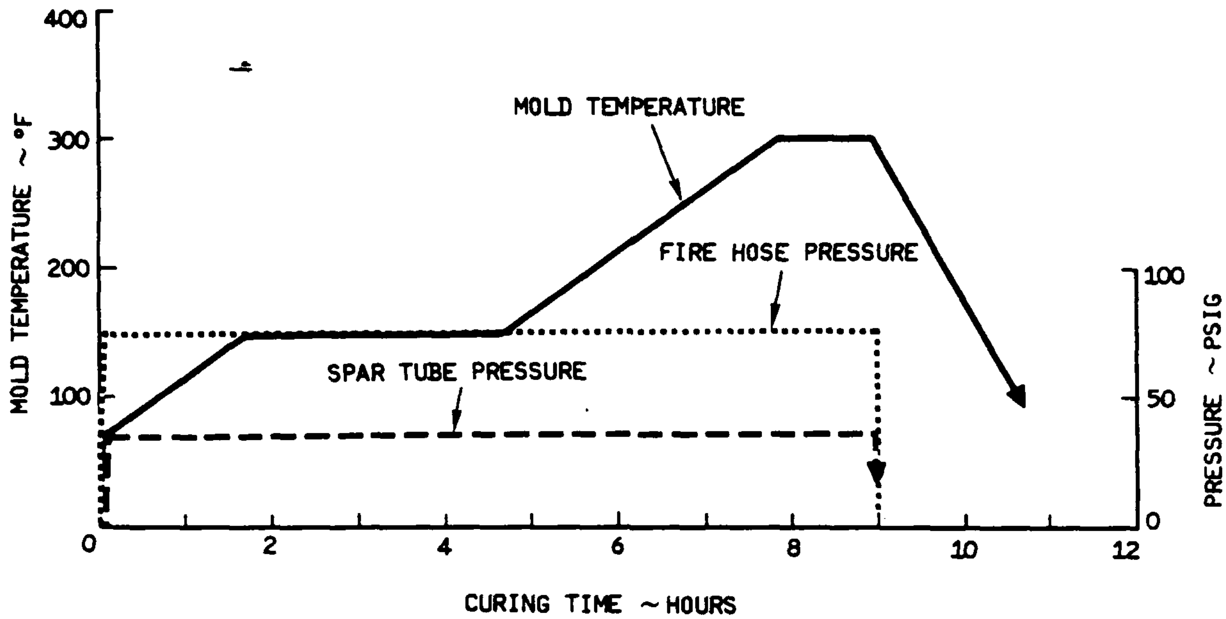


FIGURE MTR-13. CMRB TEMPERATURE/PRESSURE/TIME CURE SCHEDULE

Figure 20. CMRB temperature/pressure/time cure schedule.

- Fiberglass Reinforcement, woven cloths - inexpensive, used in secondary applications only. Example: root end closures and wedges. (MIL-C-9084.)

- Nomex honeycomb core - lightweight shear tie for increased stiffness in aft portion of blade. No corrosion problems as core is nonmetallic. (HMS 16-1114.)

- Polyurethane Foam - foam in place capabilities for increased freedom. Capable of being set at room temperature, cured at elevated temperature, to avoid expansion during final blade cure, and subsequently incorporated into blade tip area and final cured at 300°F. (HMS 17-1175.)

- E-glass milled fibers - used to add body and strength to thin (low viscosity) resin systems for filler applications. As an additive in resin, it lowers the overall density (weight). (Commercial buy 1/32 inch long.)

- Film Adhesive, Hysol EA 9628 - second generation film adhesive, 250°F curing, capable of compatible cocure with APCO resin systems as proven by lab testing 5000 pounds per square inch shear strength on aluminum adherends. 30 Pli T-peel strength on aluminum adherends. Used on current metal blade design in similar application core to skin. (HMS 16-1111, Class 6; 0.045 pound/square foot.)

- Foaming Adhesive - qualified to same specification as above, used on metal blade program in similar application core splices and core butt joints. (HMS 16-1111, Class 4.)

- Paste Adhesive, Hysol EA 934 NA - room temperature curing excellent elevated temperature properties. Long history in Aerospace as structural paste adhesive. Used in secondary bonding operations only. (HMS 16-1068, Class 3.)

- Polyurethane Erosion Strip - Estane Elastomer with and associated bonding materials tested out the best during rain and sand whirl tests of 3 foot test blades. EPB 16-139 for application of errosion strip. (HMS 17-1172, Polyurethane elastomer and HMS 17-1171, Cement.)

- Deice Blanket - Beryllium copper heating elements encapsulated between two layers of rubber modified film adhesive. The adhesive is a derivative of the EA 9628 family with approximately 40 percent hycar rubber added for flexibility to aid manufacturing sequence. Entire process is controlled in separate EPB 15-148.

METALLIC COMPONENTS

- 17-4 PH stainless root end bushings and forward weight retention fitting - corrosion resistant high temperature properties, high strength.

- Tungsten tip weight - high density used as weight in tip end. (MIL-T-21014.)

- 316 Cres - used in LE balance weight assembly. Corrosion resistant, readily available in 3/32 inch diameter as welding rod. (QQ-W-423.)

- 301 Cres - used as LE backing strip material. Readily available in sheet stock. Corrosion resistant easily formable.

- A356-T6 Aluminum - aft weight retention fitting. Material easily castable and good strength. (MIL-A-21180, Class II.)

- Aluminum wire mesh - used for lightning protection. Lightweight, conductive and easily formable. Generally acceptable in industry as lightning protection system. 5056 al twill mesh.

QUALITY CONTROL

HHI's Quality Engineers and Inspectors examined each of the MM&T blades for conformity to design and blueprint tolerances. This included in-process, shop-floor inspection at each step in the fabrication process that was specified for inspection by Manufacturing Planning, Design, and Materials and Process Engineers. Each finished blade was measured for contour, twist, waviness, and bow, and was inspected for visible surface flaws or defects. The entire blade was x-rayed with special attention being given to the root end around the retention lugs. Selected portions of the blade were examined by ultrasonics. Complete records of measurements and evaluations were filed for ready accessibility. In each case, the quality of the blade was found to be acceptable for the test that it was planned to undergo.

STRUCTURAL VERIFICATION TESTS

Tests were made in HHI's Structures Test Laboratory to verify that the CMRB manufacturing techniques were satisfactory from a static and fatigue load standpoint. These tests included:

- Static tests
  - Root-midspan
  - Swept tip
- Ground-air-Ground (GAG) tests
  - Root-midspan
  - Swept Tip
- Fatigue
  - Root
  - Swept Tip

In each case, appropriate test sections were cut from full-scale blades and doublers were bonded on so that test loads could be introduced. Strain gages were attached to the test specimens for determining the level of and distribution of loads.

ROOT-MIDSPAN STATIC TEST

The test specimen was installed in a 400,000 pound capacity Universal Testing machine (Figure 21), with an axial load applied as indicated in Figure 22 to the levels shown in Table 1. The specimen passed the limit load test and reached 149 percent of limit load (goal was 150 percent) before a failure occurred in the bonded-on doubler area. The blade was considered to have passed the ultimate load test.

Figure 21. Root-midspan static test.

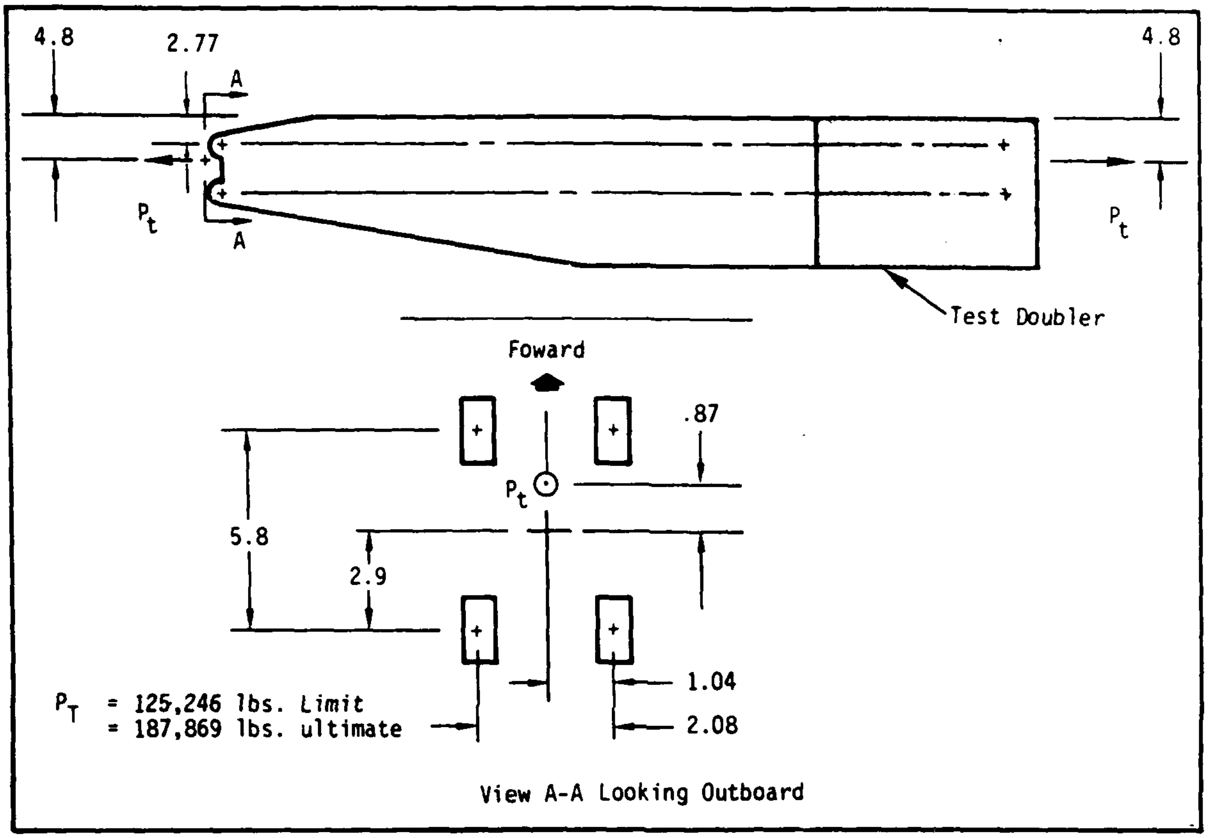


Figure 22. Load configuration, root-midspan static test.

TABLE 1. ROOT-MIDSPAN STATIC TEST RESULTS

Load Sequence	Comments
125,200 lb Limit Load	No failure or apparent yielding.
25,000 lb 20% Limit	Apparent set due to hysteresis.
0	No measurable permanent set.
186,000 lb	Failure at 149% limit load, with failure occurring in test doubler area outboard of test section.

SWEPT TIP STATIC TEST

An axial load test was made in the Universal test machine with the setup shown in Figures 23 and 24. The loads were applied in a manner to load the entire tip structure and also to pull on the tip weights. The tip sustained 356 percent of limit load before one of the load application pads failed as described in Table 2 and dumped the entire load into remaining weight. A second test used a hydraulic jack to try to pull the aft tip weight out of the bottom of the blade. Figures 25 and 26 show the setup and Table 2 shows that the ultimate load was carried satisfactorily.

ROOT-MIDSPAN GROUND-AIR-GROUND (GAG) FATIGUE TEST

This GAG test was made to simulate rotor start/stop cycles. This setup is shown in Figures 27 and 28. It used a programmed hydraulic actuator to apply axial loads cyclically at rate of 1.0 Hz. 108,000 cycles were applied to simulate eight times three GAG cycles per hour and represent a 4500-hour service life, plus a good margin. During this test the blade experienced the bending moments shown in Figure 29. The load was then increased 25 percent and the test was continued for another 33,200 cycles until damage was sustained in one of the lug fittings. Table 3 summarizes the test results. Note that with the one lug damaged, the blade still carried the required axial load.

SWEPT TIP GROUND-AIR-GROUND (GAG) TEST

This blade segment was subjected to cyclic loads at a frequency of 5 Hz, applied by a hydraulic actuator. A whiffletree distributed the loads to P_1, P_2, and P_3 as shown in Figure 30. The setup was also used for the swept tip fatigue test that is described in a following section. This test ran for 110,500 cycles (108,000 cycles represents eight times the 4500 hours service life) with no damage. Bending moments measured during the test are given in Table 4.

ROOT FATIGUE-MIDSPAN TEST

The root fatigue test was conducted in a fixture that applied simulated centrifugal force by an air bag, and bending moments and torsion by servo-controlled hydraulic cylinders. Strain gages were attached to the blade as Figure 31 shows. Masses added at the ends of the test specimen tuned the assembly to allow it to be driven in a flapwise resonant condition at a frequency of 13 Hz which was determined to be too high and to be unrealistic.

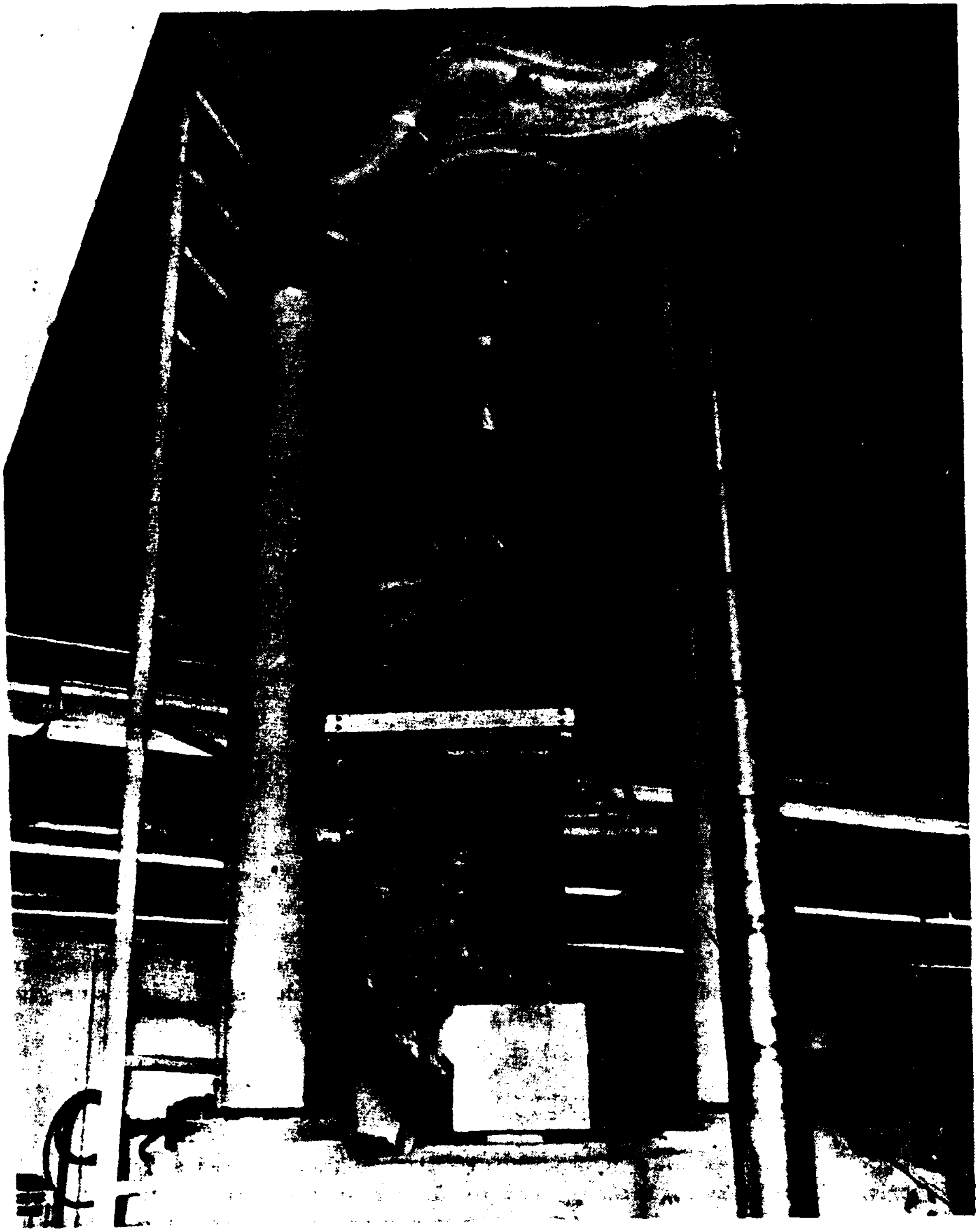
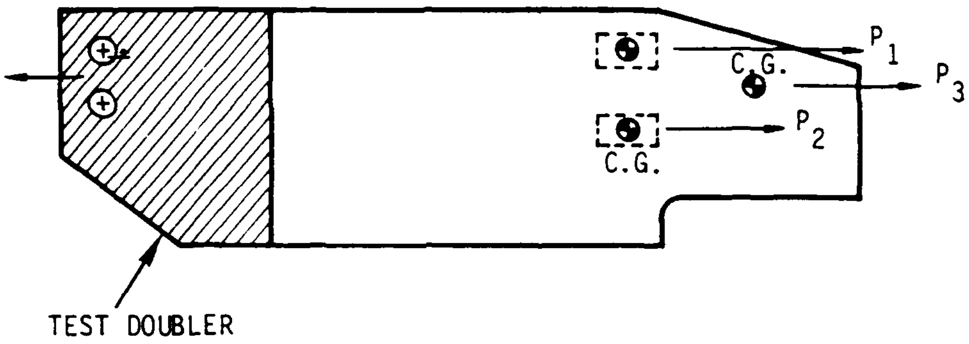


Figure 23. Test setup, swept tip radial static test.



	LIMIT LOADS (LBS)	ULTIMATE LOAD (LBS)
P_1	13,180	19,770
P_2	4,330	6,500
P_3	12,020	18,030

Figure 24. Load configuration, swept tip radial static test.

TABLE 2. SWEPT TIP RADIAL AND AFT TIP WEIGHT VERTICAL STATIC TEST RESULTS

Load Sequence (lb)	Results
29,500: Radial Combined	Limit load. No failure
0	Zero measurable permanent set.
62,400: Radial Combined	Swept Tip Pad (P3) failed.
47,000: Radial P1 only	356% limit load. No failure.
15,400: Radial P2 only	356% limit load. No failure.
848: Vertical	Limit load. No failure.
0	Zero measurable permanent set.
1,270: Vertical	Ultimate load. 3 seconds. No failure.
0	Zero measurable permanent set.

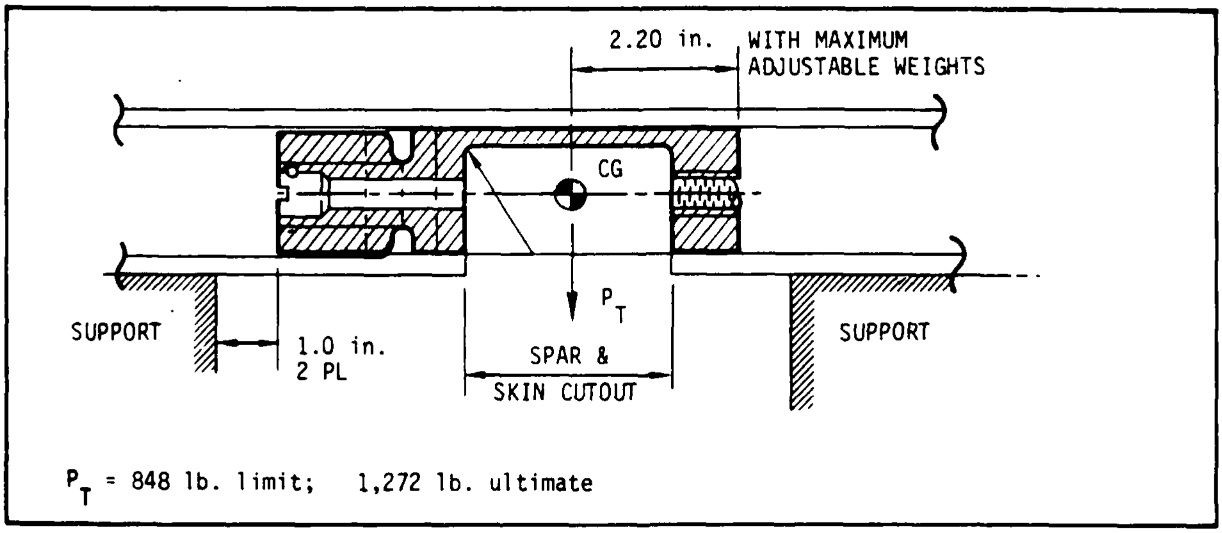


Figure 25. Load configuration, aft weight assembly, vertical load test.

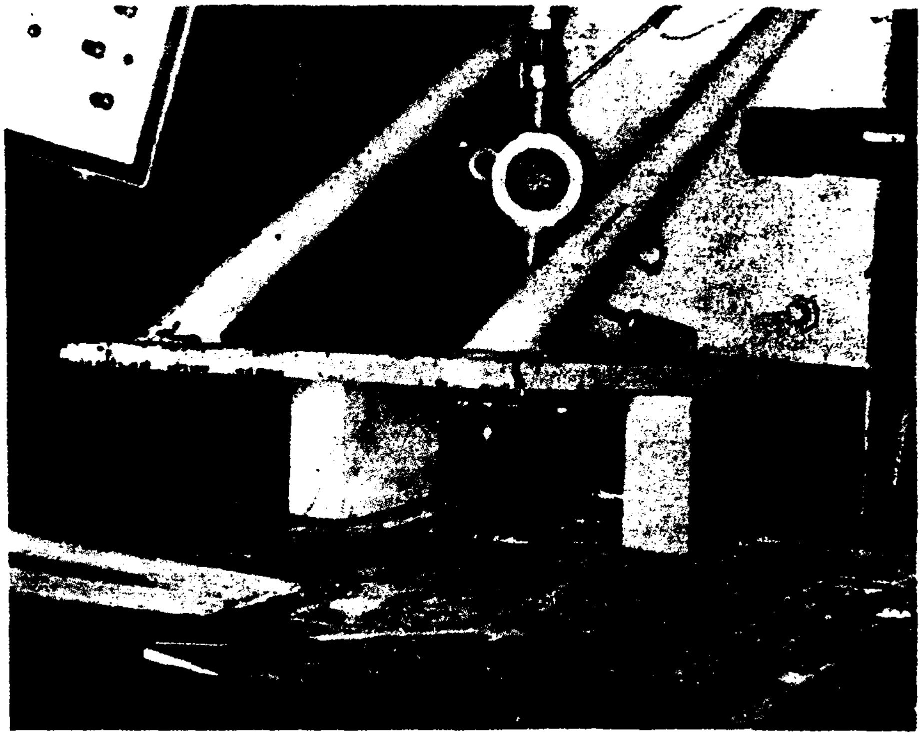


Figure 26. Test setup, aft tip weight assembly vertical static test.

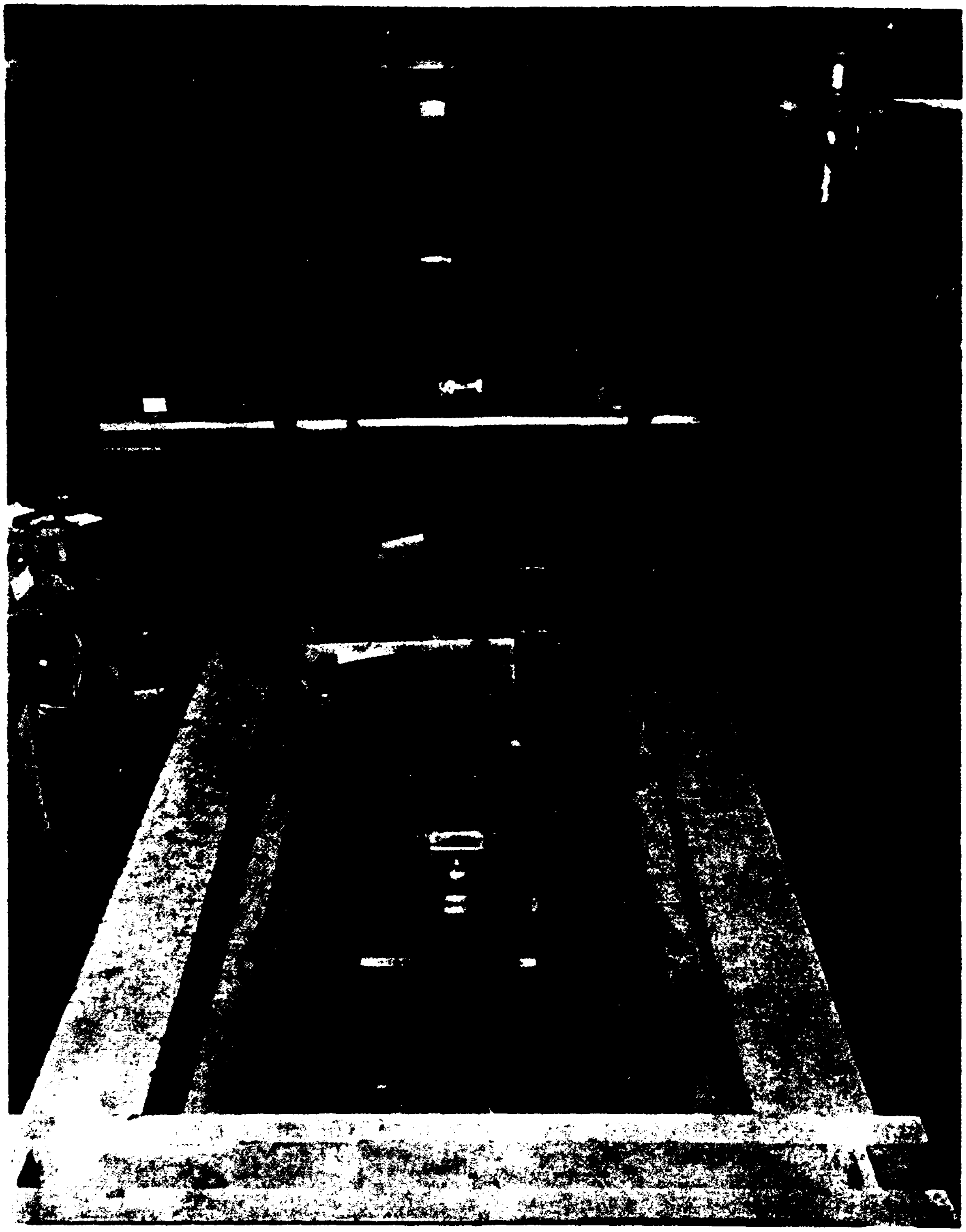


Figure 27. Root-midspan GAG test.

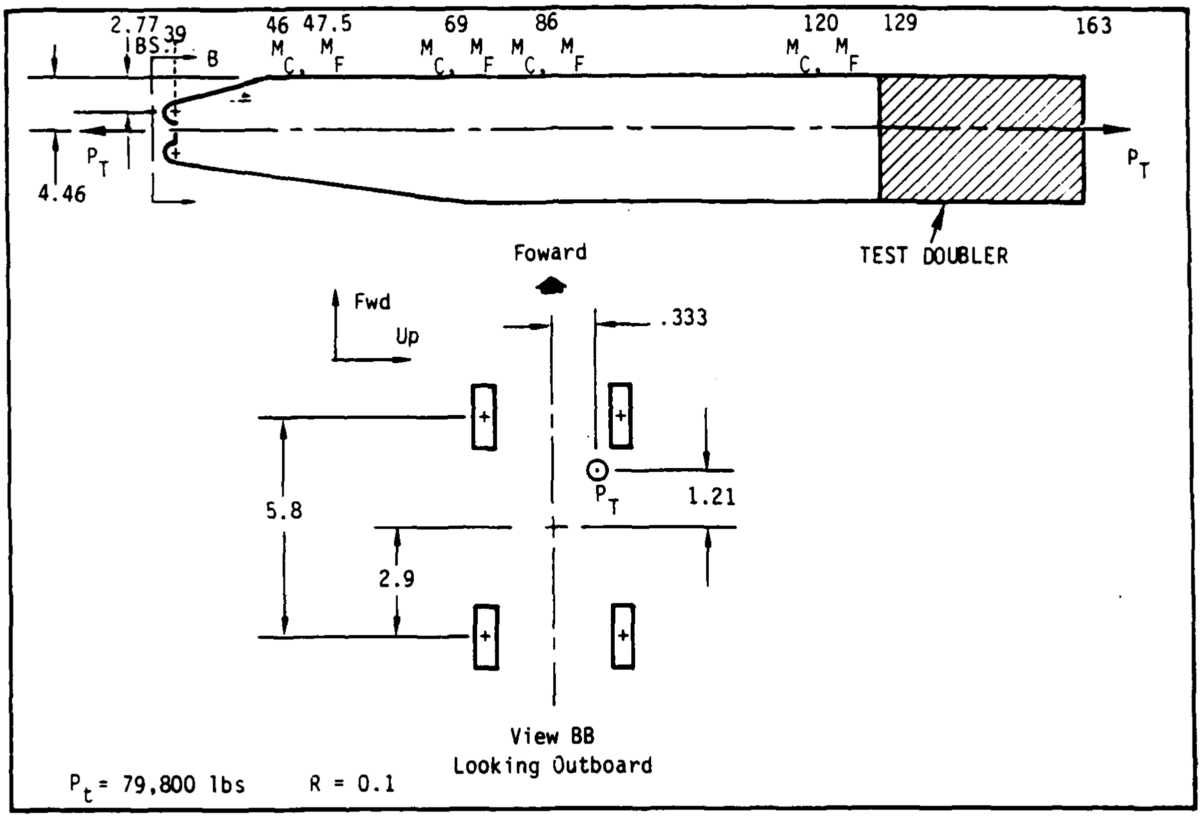


Figure 28. Load configuration, root-midspan GAG test.

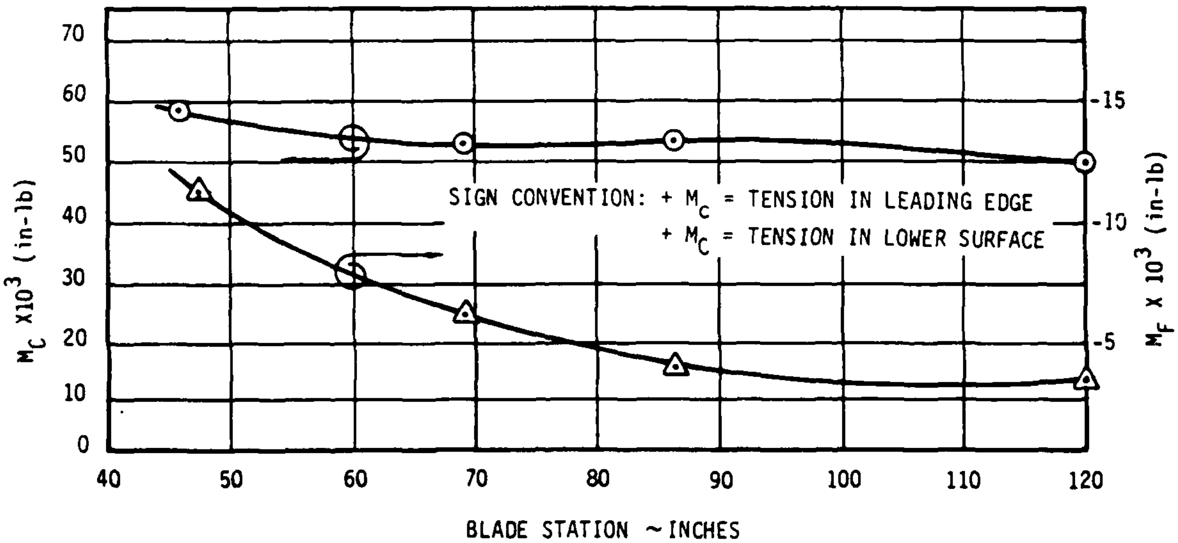


Figure 29. Bending moment distribution at load level 1 root-midspan GAG test.

TABLE 3. TEST RESULTS ROOT-MIDSPAN GAG TEST

Load (R = 0.1)		Cycles Completed	Test Results
Level	Lb		
1	79,800	108,000	No detectable damage.
2	99,750	8,000	Heat build up Station 55. Yielding of Forward Upper Longos.
2	99,750	33,200	Failure of Forward Upper lug at Station 39.

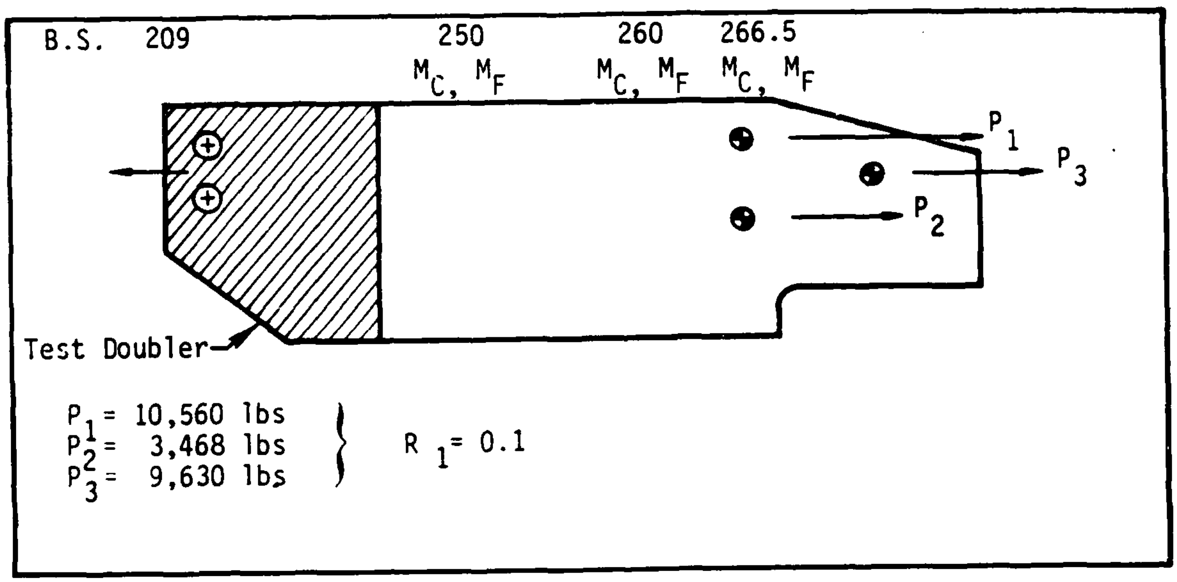


Figure 30. Load configuration, swept tip GAG test.

TABLE 4. BENDING MOMENTS, SWEPT TIP GAG TEST

Test Cycle Count	Blade Station (in)	M_C (in-lb)	M_F (in-lb)
1,700	250	-9,410	-1,480
	260	-38,100	-1,530
	266.5	+97,500	+3,000
30,000	250	-13,950	-1,430
	260	-26,700	-1,450
	266.5	+90,900	+2,570

Sign Convention: + M_C = Tension in leading edge

+ M_F = Tension in lower surface

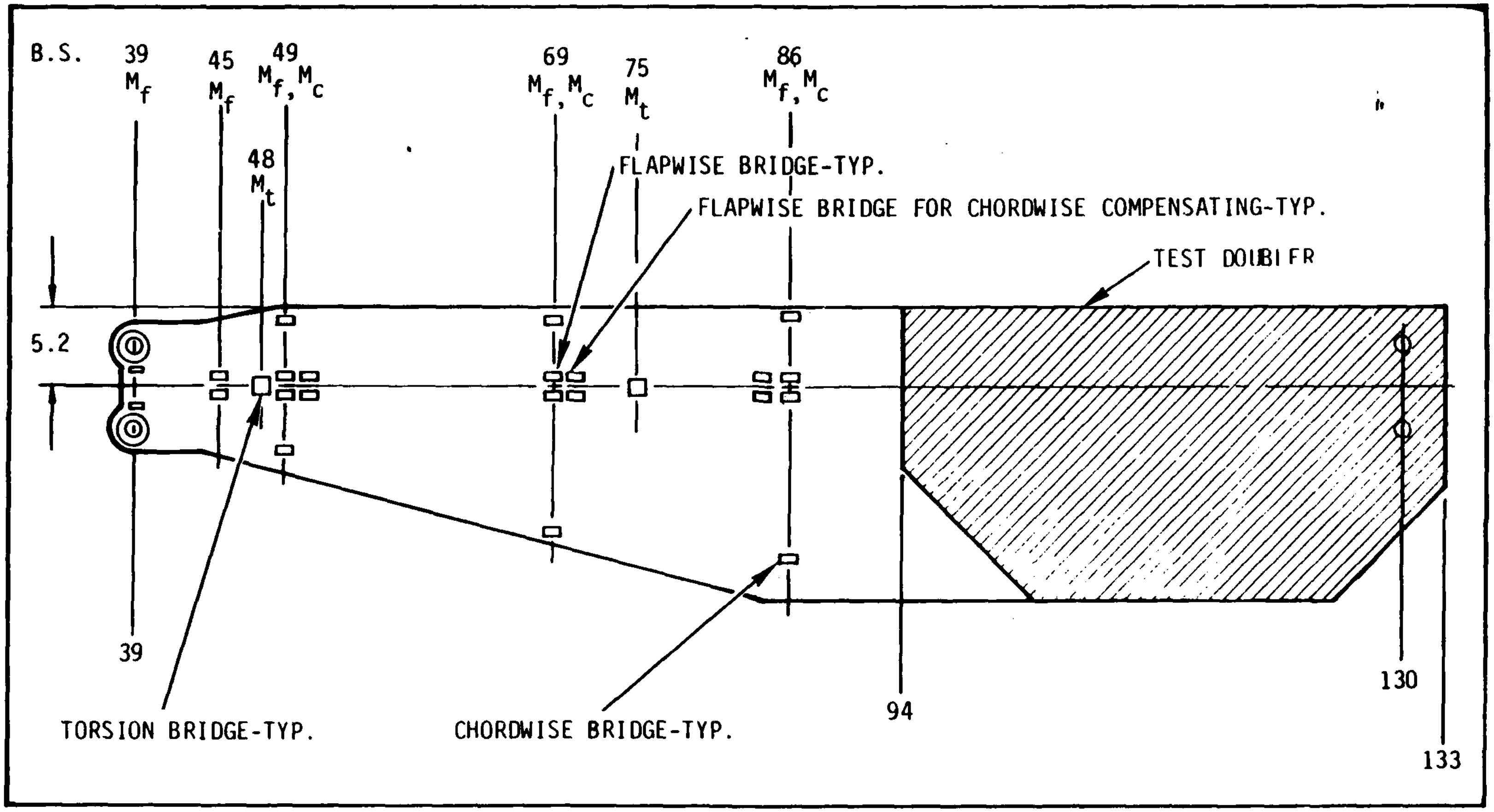


Figure 31. Strain gage bridge locations, root fatigue test.

The first two specimens tested at this frequency experienced excessive heating in the retention lug area and had premature failure in this region. Consequently, the test rig was revised before continuing the tests. Figure 32 is a schematic of the reworked test facility. Two major improvements are the addition of waterbags along the specimen to distribute uniform flapwise shear loads into the blade, and lowering the vibration frequency to 2 Hz. Specimen No. 3 was the first to be tested in the revised test rig. Tests began at Load Level (LL)-1 as defined in Table 5, and ran for 733,000 cycles before the forward lower lug bushing-to-blade bonding failed and allowed the bushing to rotate. The load level was changed to LL-2 and the frequency was raised to 5 Hz to determine if overheating would occur in the lug area at normal flight loads and frequencies. The chordwise load phasing was reversed to shift the maximum loads away from the damaged lug. The test ran for 79,400 cycles in 4 hours with the lug temperature stabilizing at 106°F. Then the loads were raised to LL-3 at 1.5 Hz for 2100 cycles at which time all the bushings were observed to have become unbonded, the lugs to have increased in thickness, indicating a failure in the epoxy matrix material in the lugs, and damage to have occurred to the longos in the lower forward lug.

Specimen No. 4 incorporated an increased number of longos around each bushing. It was tested at LL-4 (Table 5) for 10^6 cycles, and again showed increased thickness in the lug area indicating a matrix failure. The bushings were still bonded at this point. The loads were raised to LL-5, and after 73,200 cycles all four bushings had become unbonded.

The reduction in the strength of the longo/bushing configuration was evaluated by the fan belt (looped unidirectional filament) tension-tension fatigue test made with the two specimens described in Figure 33. One specimen had spools with plain flanges. The other had a groove cut around the base of one flange as Figure 33 shows. This groove weakened the flange and when it was no longer able to support the longos, the longos' load-carrying ability and cycles-to-failure decreased severely. As a result, the CMRB root bushings were redesigned to be double-flanged spools to support the longos and the No. 5 specimen was modified for its fatigue tests.

Specimen No. 5 was identical to No. 4 but was mounted in the lead-lag link with shims installed between the lugs and the lead-lag link to furnish support for the longos in the lug area to simulate the effect of the double-flanged bushing (Figure 7). After 258,000 cycles at load level 5, a delamination of the lower surface skin from the honeycomb filler in the aft blade region at Station 86 occurred. At 888,200 cycles, the leading edge cracked between Stations 86 and 94. At 897,300 cycles the skin cracked from Station 52 on the upper surface around the nose of the blade to Station 55 on the lower surface. After repairing both of the leading edge skin failures, the loads

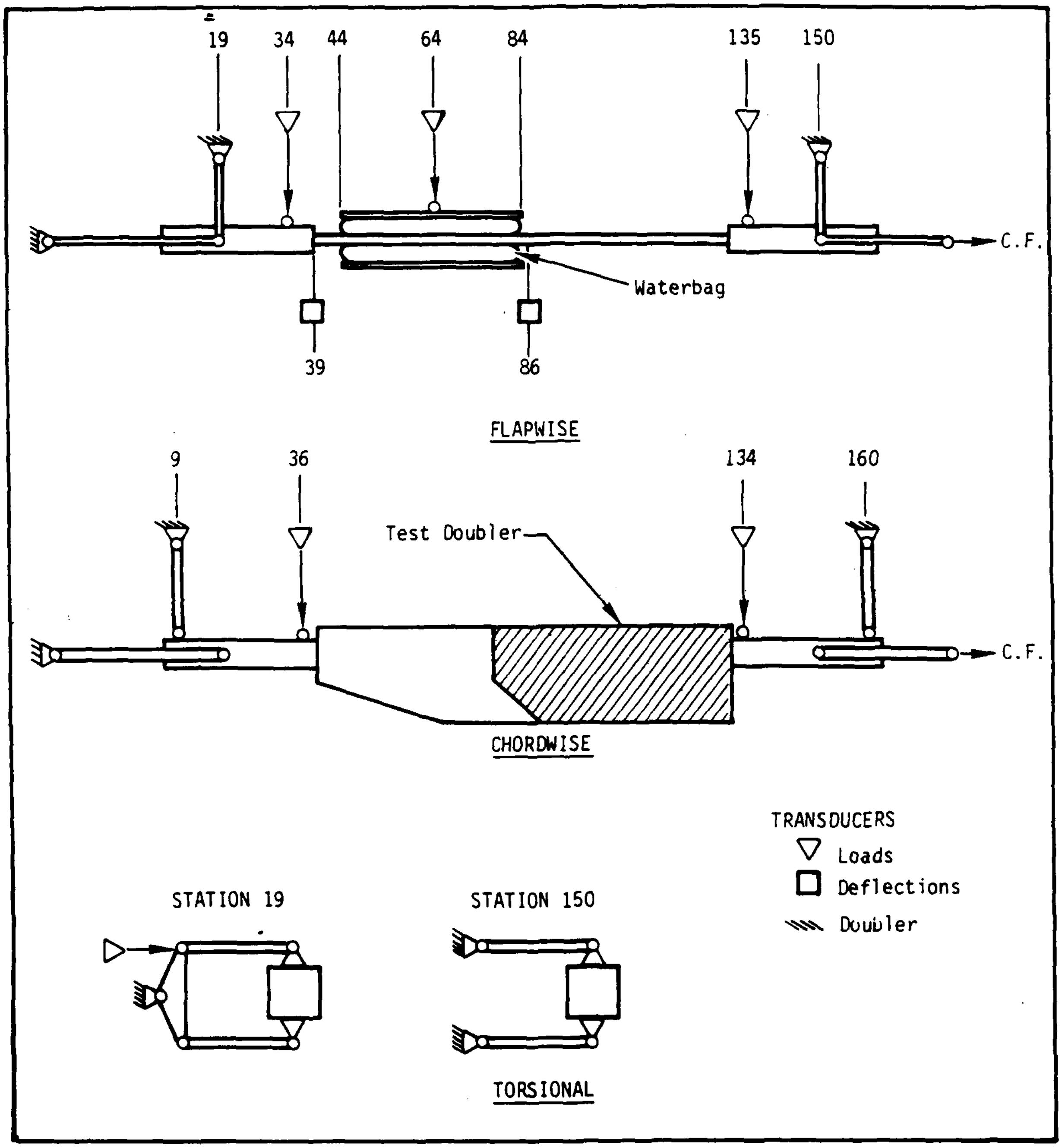


Figure 32. Load schematic, root fatigue test.

TABLE 5. CYCLIC LOAD SUMMARY, ROOT FATIGUE TEST

Load Type	Blade Station	Spec. 3 LL-1(4)	Spec. 3 LL-2	Spec. 3 LL-3	Spec. 4 LL-4	Spec. 4 LL-5	Spec. 5 LL-5	Spec. 5 LL-6
M_F	39	±39,200	±15,600	±50,960	±39,200	±43,950	±43,950	± 54,500
(in-lb)	49	±33,100	±14,400	±46,800	±36,000	±40,360	±40,360	± 50,000
	69	±35,200	±11,400	±40,100	±30,000	±30,800	±31,500	± 40,300
	86	±24,100	± 5,600	±34,800	±16,000	±18,400	±20,400	± 32,000
M_C	39(1)	±50,400	∓20,160	∓65,500	±50,400	±87,900	±87,900	±109,000
(in-lb)	49	±51,900	∓20,760	∓64,100	±52,500	±85,100	±85,000	± 96,800
	69	±55,900	∓22,360	∓61,400	±55,900	±79,400	±79,300	± 72,400
	86	±53,000	∓21,200	∓69,550	±53,500	±93,300	±93,300	± 57,000
M_T	39(2)	± 8,390	± 3,356	±16,800	±13,850	±18,500	±18,500	± 23,100
(in-lb)	48	± 7,990	± 3,196	±16,550	±13,600	±18,200	±18,300	± 22,400
	75	± 6,800	± 2,720	±15,800	±13,000	±17,400	±17,600	± 20,300
	86(3)	± 6,800	± 2,720	±15,800	±13,000	±17,400	±17,600	± 10,300
C_F (lb)	C. F.	60,420	60,420	60,420	60,420	60,420	60,420	60,420

Notes:

(1) Chordwise load at Station 39 determined by linear extrapolation of measured loads at Stations 49 and 69.

(2) Torsional load at Station 39 determined by linear extrapolation of measured loads at Stations 48 and 75.

(3) Torsional load at Station 86 assumed to be the same as the measured load at Station 75.

(4) LL-x indicates Load Level number.

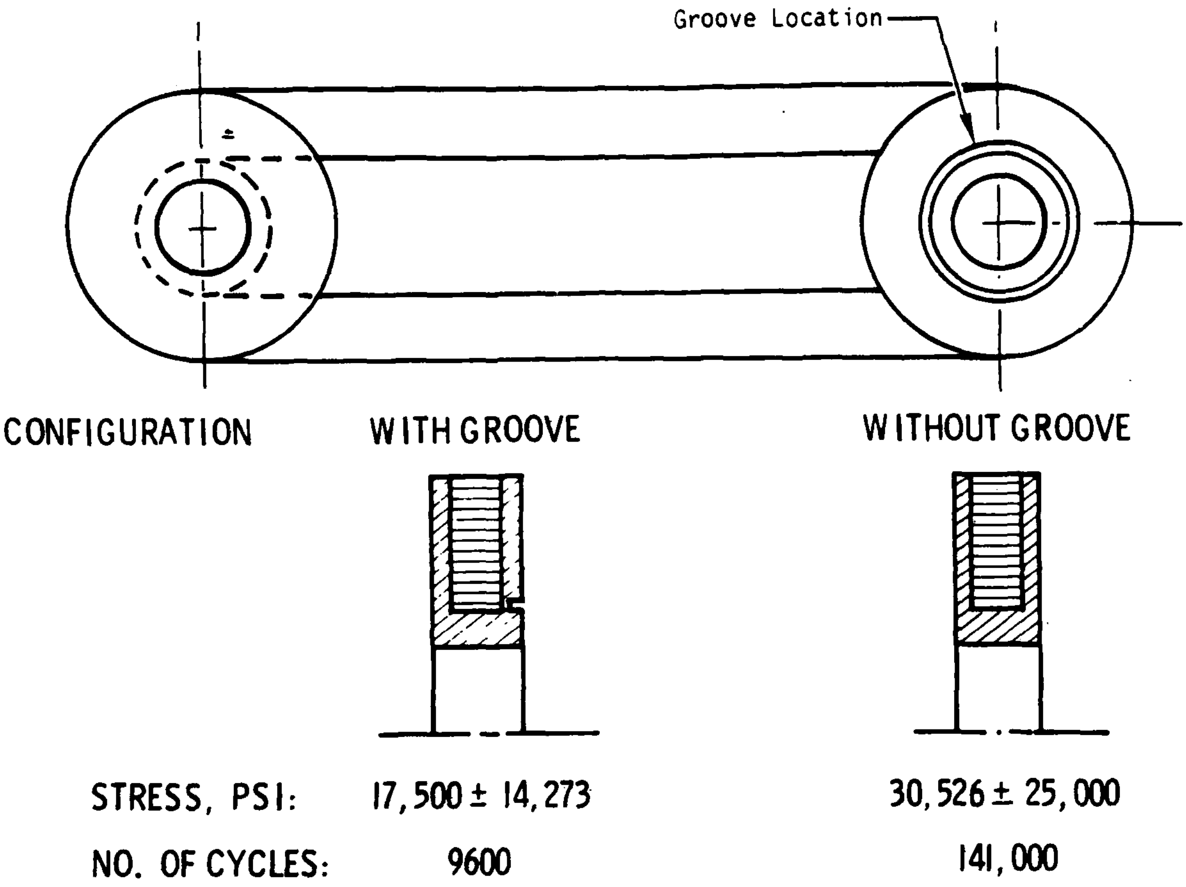


Figure 33. Fanbelt test specimen — grooved flange.

were raised to load level 6 and testing was resumed. After 50,400 cycles, the measured specimen deflection at Station 39 had increased to 110 percent of that obtained at the start of load level 6 and testing was stopped. Inspection of the specimen revealed no visible damage to the lugs or to the rest of the blade and it was assumed that the loss of stiffness was due to internal degradation of the longos outboard of the lugs. Load level 6 represents the 1-hour load level and is required to be sustained for 17,340 cycles (approximately one-third of the cycles actually tested).

The loads that were measured in these tests are summarized in Table 6 and Figures 34 through 37. Note that at the end of the test for each specimen (Nos. 3, 4, and 5), the root end of the blade could still support the centrifugal force.

TABLE 6. TEST RESULTS ROOT FATIGUE TESTS

Specimen No.	Load Level	Cycle Count		Test Rate (CPS)	Comments
		Total	Delta		
3	1	733,100	733,100	2.0	Lower forward lug bushing rotated.
	2	812,500	79,400	5.0	Max temp of 106°F at upper fwd lug.
	3	814,600	2,100	1.5	All bushings loose with severe fretting. Lower fwd lug failed. Lateral expansion of all lugs present.
4	4	1,000,000	1,000,000	2.0	Lateral expansion of lugs.
	5	1,073,200	73,200	2.0	Upper aft and lower fwd lugs loose. Increased lateral expansion of lugs.
5	5	258,800	258,800	2.0	Delamination of skin from Honeycomb at Sta. 86.
		888,200	629,400	2.0	Leading edge skin cracked from Sta. 86 to Sta. 94.
		897,300	9,100	2.0	Leading edge skin cracked from Sta. 52 upper surface to Sta. 55 lower surface. All cracks repaired.
	6	947,700	50,400	2.0	Deflections at Sta. 39. 110%. Lugs intact. Damage internal.

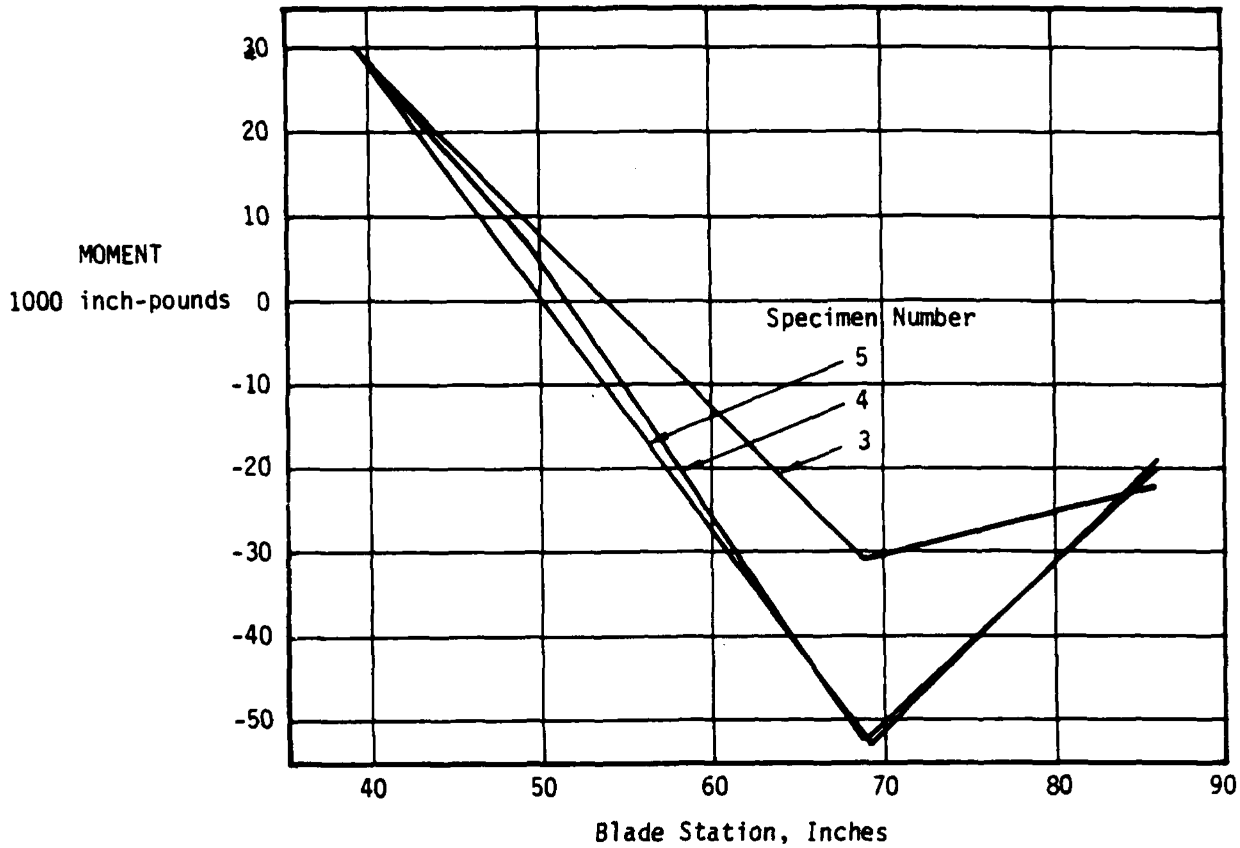


Figure 34. Steady chordwise moments, root fatigue tests, specimens 3, 4, and 5.

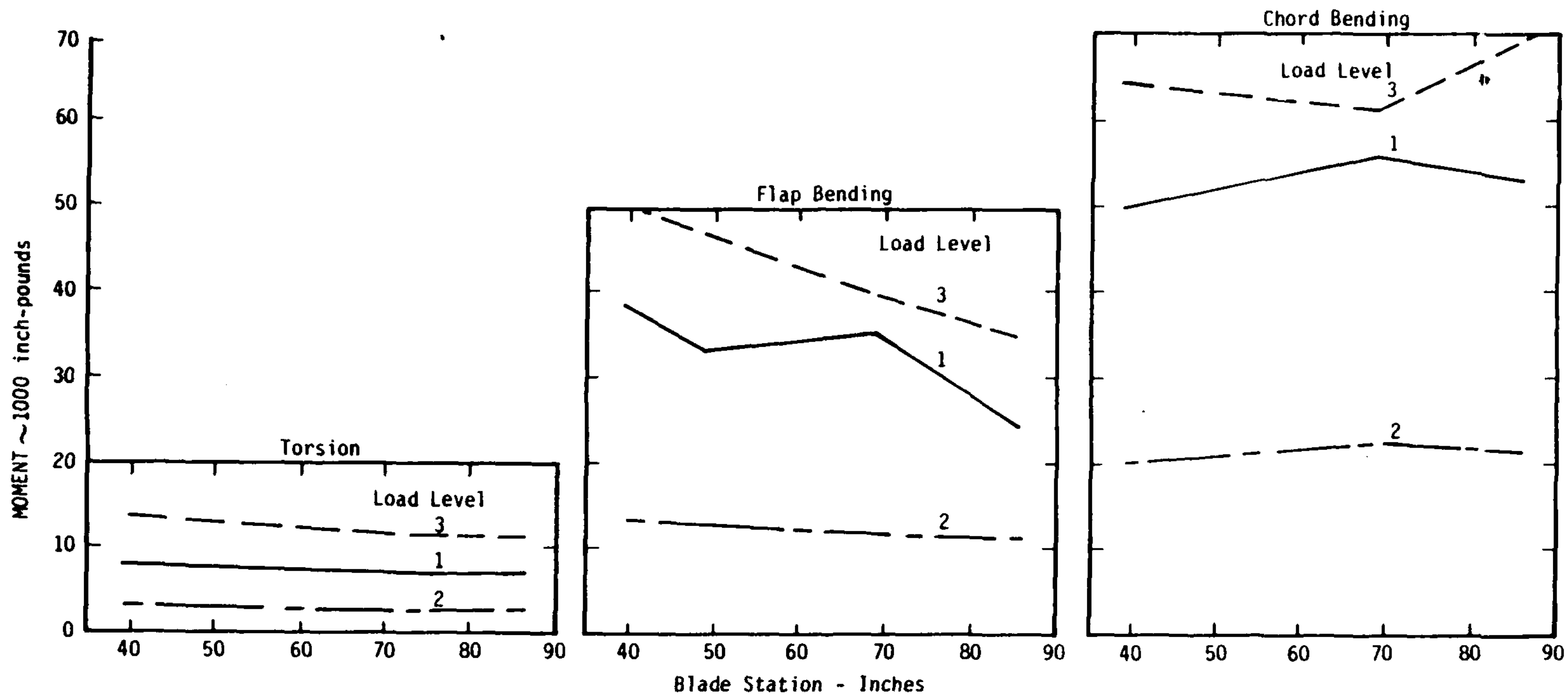


Figure 35. Load distribution, root fatigue specimen No. 3.

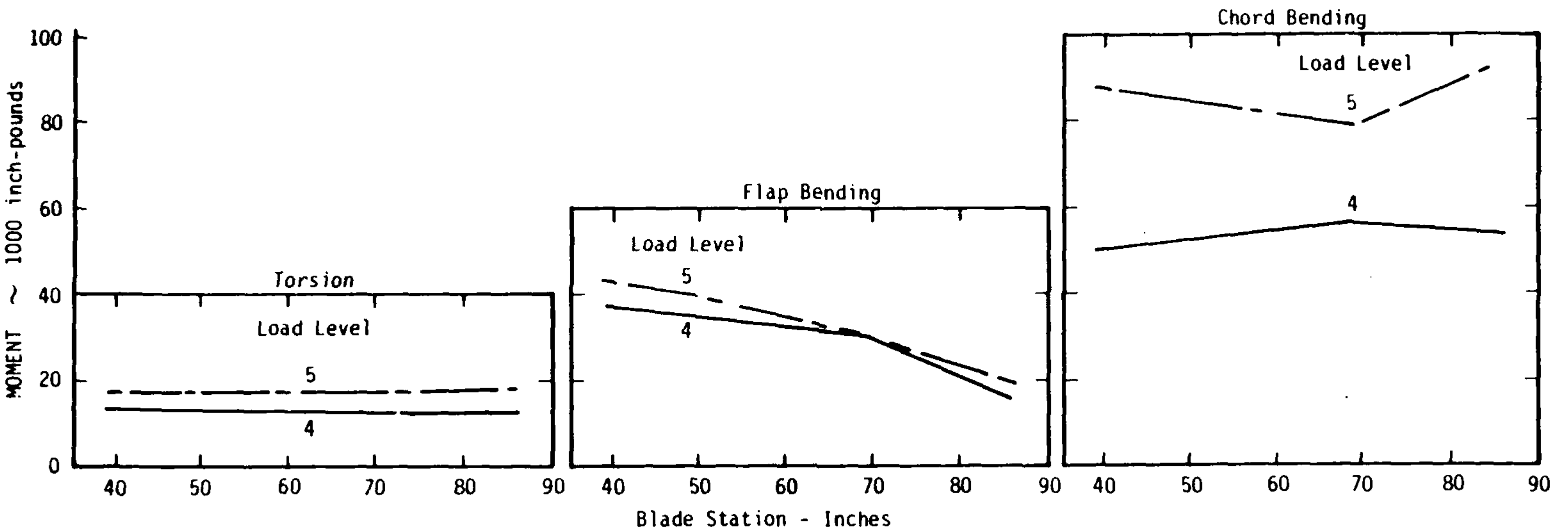


Figure 36. Load distribution, root fatigue specimen No. 4.

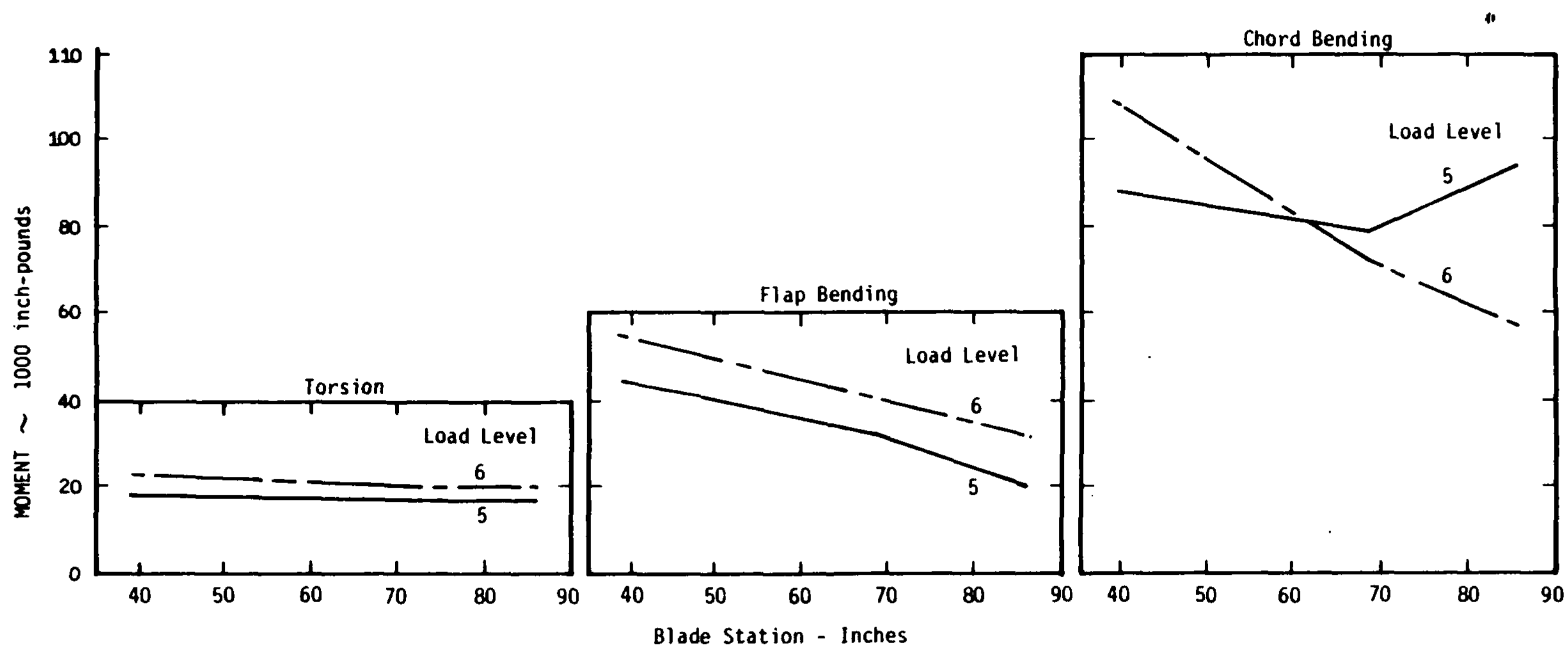
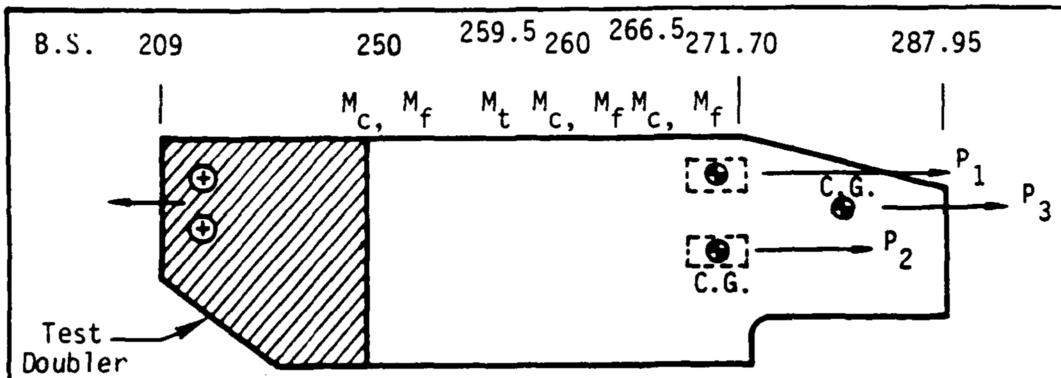


Figure 37. Load distribution, root fatigue specimen No. 5.

SWEPT TIP FATIGUE TEST

The same test set up used for the swept tip GAG test was used for the swept tip fatigue test except that an air cylinder was added to furnish the simulated steady centrifugal force. Two hydraulic cylinders were positioned to induce flapwise bending, chordwise bending, and torsion. Figure 38 shows the test setup and loading conditions.

The test ran for one million cycles at a weighted fatigue load without damage as Table 7 shows. The cyclic loads were increased 25 percent and another million cycles were imposed, again without damage. The cyclic loads were then increased to a level 50 percent greater than the initial loads. The test was terminated after 162,000 cycles — no failure was observed. The fatigue bending moments that were measured at the initial loading condition are summarized in Table 8.



P_1 = 7,790 lb.
P_2 = 2,558 lb.
P_3 = 7,104 lb.

	Fatigue Moments at		
	STA 266.5		STA 259.5
	M_{flap} (in-lb)	M_{chord} (in-lb)	$M_{torsion}$ (in-lb)
Steady Moment	0	353	0
Cyclic Moment	±9227	±5670	±1100

Figure 38. Load configuration, swept tip fatigue test.

TABLE 7. TEST RESULTS, SWEPT TIP FATIGUE TEST

Load Level	Fatigue Moments (in-lb)			Comments
	Sta 266.5		Sta 260	
	M_{Flap}	M_{Chord}	$M_{Torsion}$	
1	± 9,230	±5,670	±1,100	1×10^6 cycles. No failure
2	±11,500	±7,090	±1,380	1×10^6 cycles. No failure
3	±13,850	±8,500	±1,650	162,000 cycles. No failure Test terminated

TABLE 8. FATIGUE BENDING MOMENT DISTRIBUTION, LOAD LEVEL 1 SWEPT TIP FATIGUE TEST

Cycles	Station (in)	M_C ±(in-lb)	M_F ±(in-lb)
5,600	250	17,000	16,650
	260	4,190	10,700
	266.5	5,670	9,200
22,590	250	17,500	16,950
	260	4,070	10,700
	266.5	5,670	9,230
29,300	250	15,300	16,750
	260	N.A.	10,700
	266.5	5,670	9,230

During the full qualification program that will follow the MM&T activities, the following tests will be conducted to demonstrate the load-carrying ability of the CMRB:

- Root fatigue (6 specimens)
- Midspan fatigue (6 specimens)
- Swept tip GAG/fatigue (6 specimens)

LIGHTNING SURVIVABILITY TESTS (HHI-SPONSORED TEST)

Three types of lightning survivability test were conducted on a 24-inch-long specimen cut from the mid-span region of a CMRB. These tests will be repeated on a full-length blade during the full qualification program.

A high voltage, long arc test that was set up as in Figure 39 resulted in the 1.5-megavolt discharge flashing over the exterior of the blade and causing essentially no damage except the small spot on the leading edge that is shown in Figure 40. A swept stroke test using the test arrangement shown in Figure 41 discharged a 100-kiloampere high-current restrike onto the midchord region of the blade and did no more damage than a 12.7 mm API projectile would do (Figure 42). However, penetration was achieved only after a small hole had been drilled through the blade surface into the underlying graphite. A 228-kiloampere high-current test was conducted on the trailing edge region of the blade where the graphite trailing edge longo is covered by an aluminum screen as Figure 43 shows. The aluminum screen was vaporized (see Figure 44) but there was no structural damage.

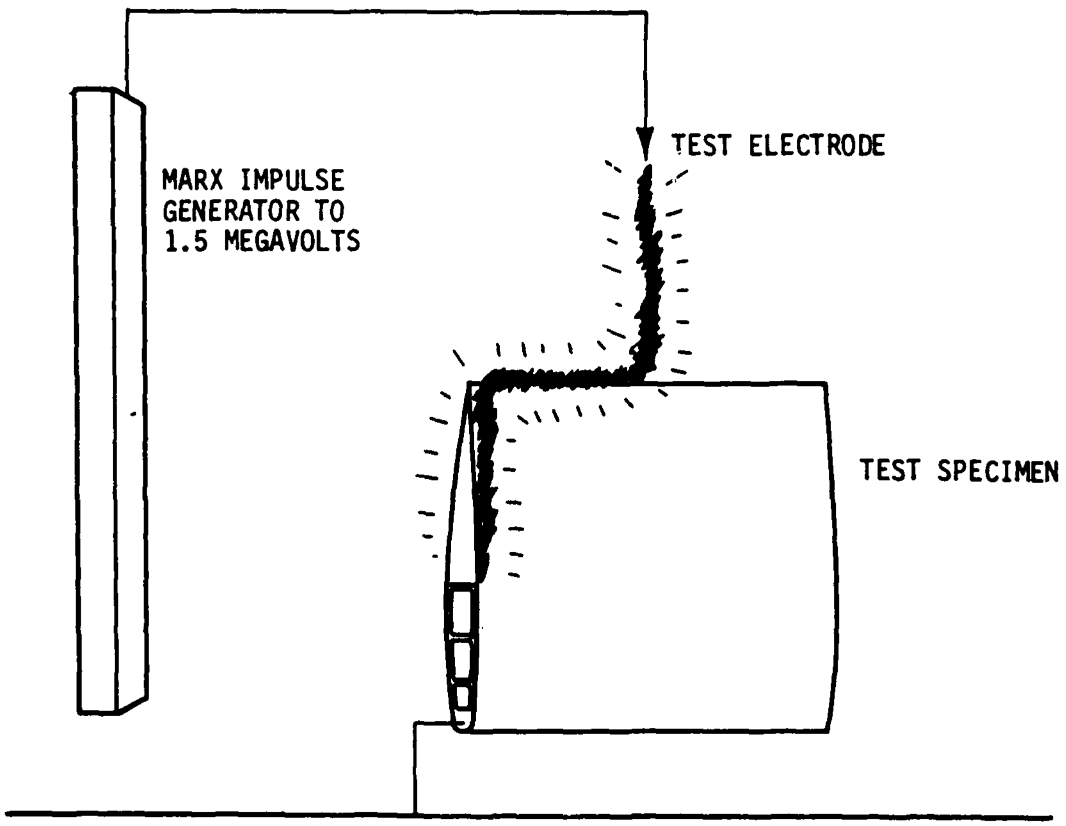


Figure 39. High voltage, long arc test of blade specimen.

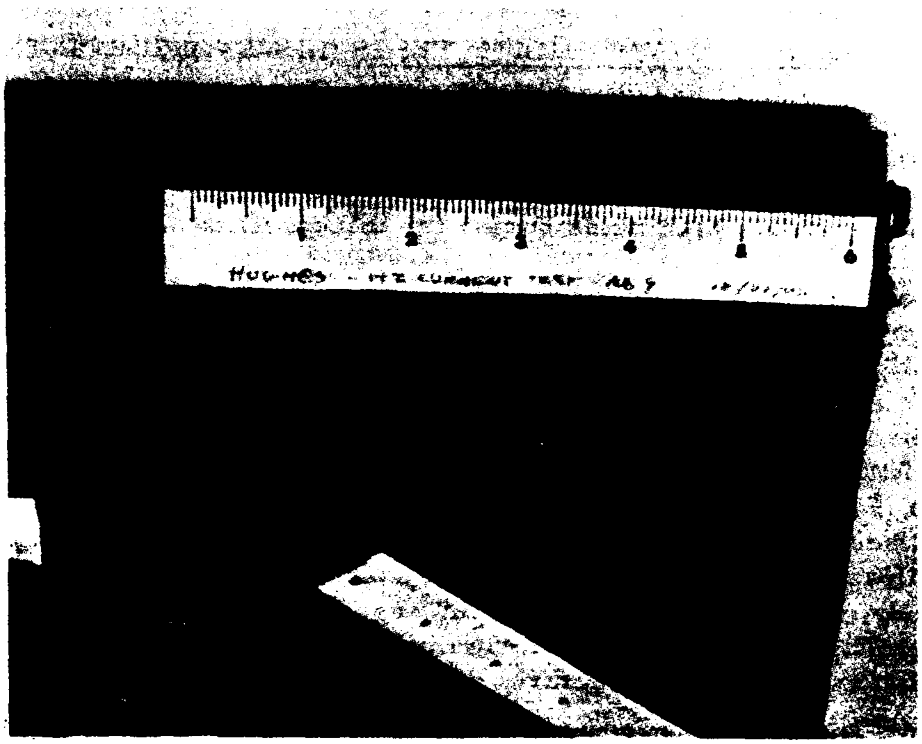


Figure 40. High voltage, long arc leading edge lightning test.

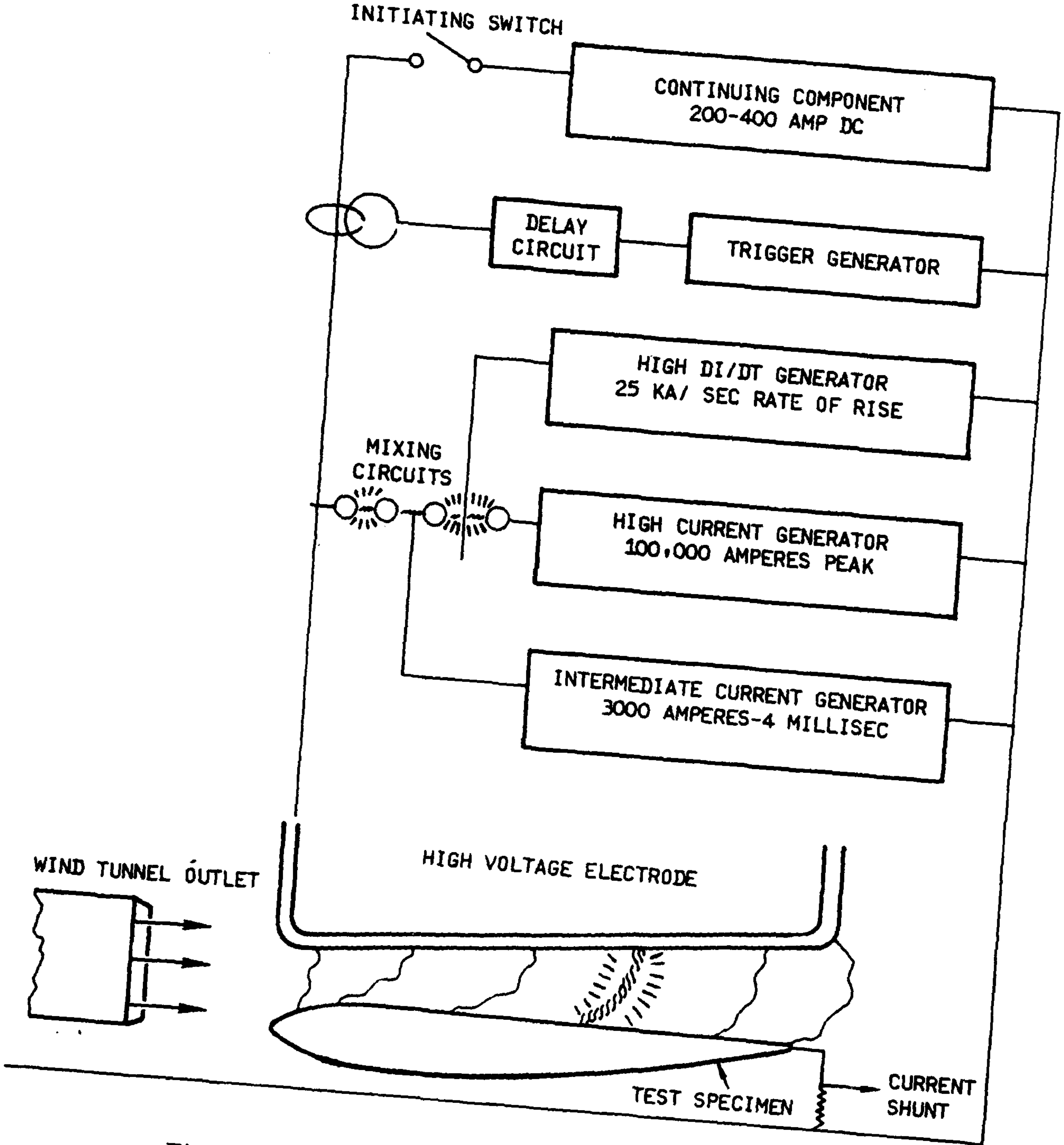


Figure 41. Test arrangement for swept stroke tests.

Figure 42. High current, swept stroke mid-chord lightning test.

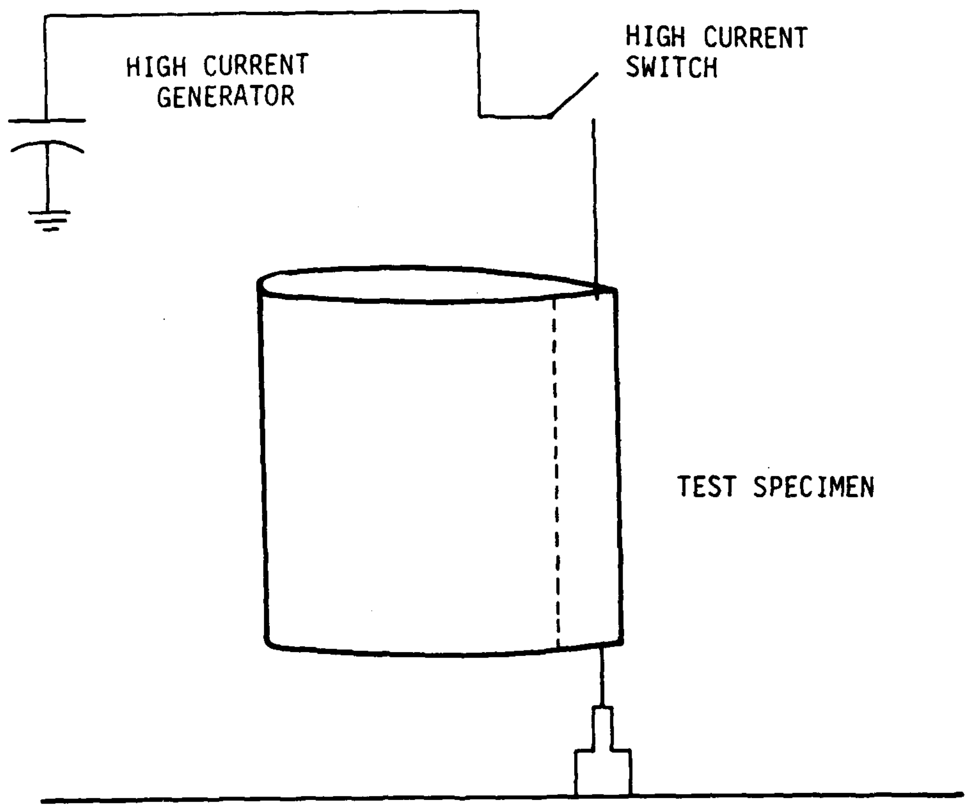


Figure 43. Stationary 200 kiloampere high current damage test of trailing edge.

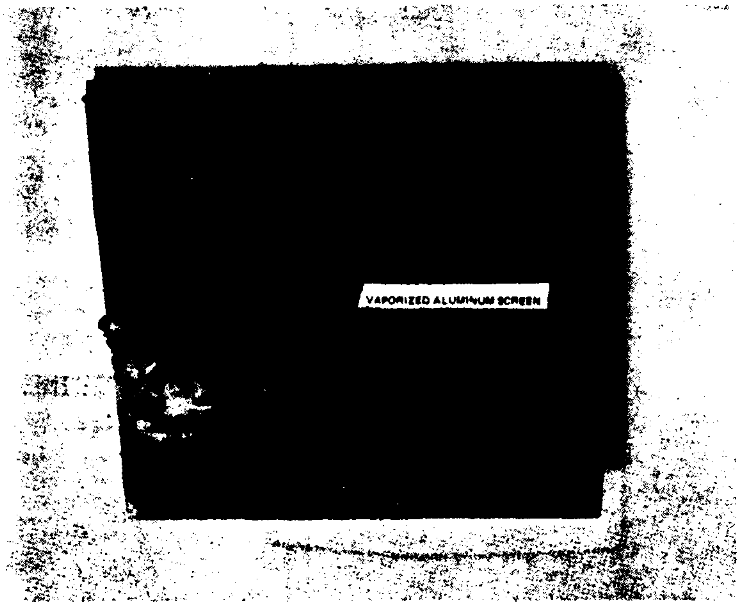


Figure 44. High current, trailing edge lightning test.

EROSION PROTECTION TEST

Three non-metallic materials were tested in HHI's rain test facility (Figure 45) to select one to protect the leading edge of the CMRB. All three were various formulations of polyurethane; each was supplied by a different vendor. Because polyurethane is well recognized as a good material for protecting against sand and dust erosion, the tests were limited to rain only. The simulated rainfall rate was one inch per hour with the droplet size distribution specified in (Reference 7).

Each candidate material was bonded to the leading edge of a modified OH-6A main rotor blade, Figure 46, and was run at AH-64A simulated tip speed. Table 9 summarizes the test results while Figures 41 through 50 show the condition of each material at the time its test was stopped. On the basis of these tests, HHI chose the BF Goodrich "Estane" material for the CMRB.

BF Goodrich provided a kit for making fairly simple repairs to erosion-damaged "Estane." After the original was found to be damaged at 95 minutes, the swept tip portion was repaired and the test continued on for another 4 hours and 25 minutes (6 hours total) with remarkably little damage. The erosion protection material inboard of the swept tip was not repaired so the original material in this region was exposed to the test environment for the full 6 hours, and did not erode through.

[7] Military Standard - CLIMATIC EXTREMES FOR MILITARY EQUIPMENT, MIL-STD-210B, 15 December 1973

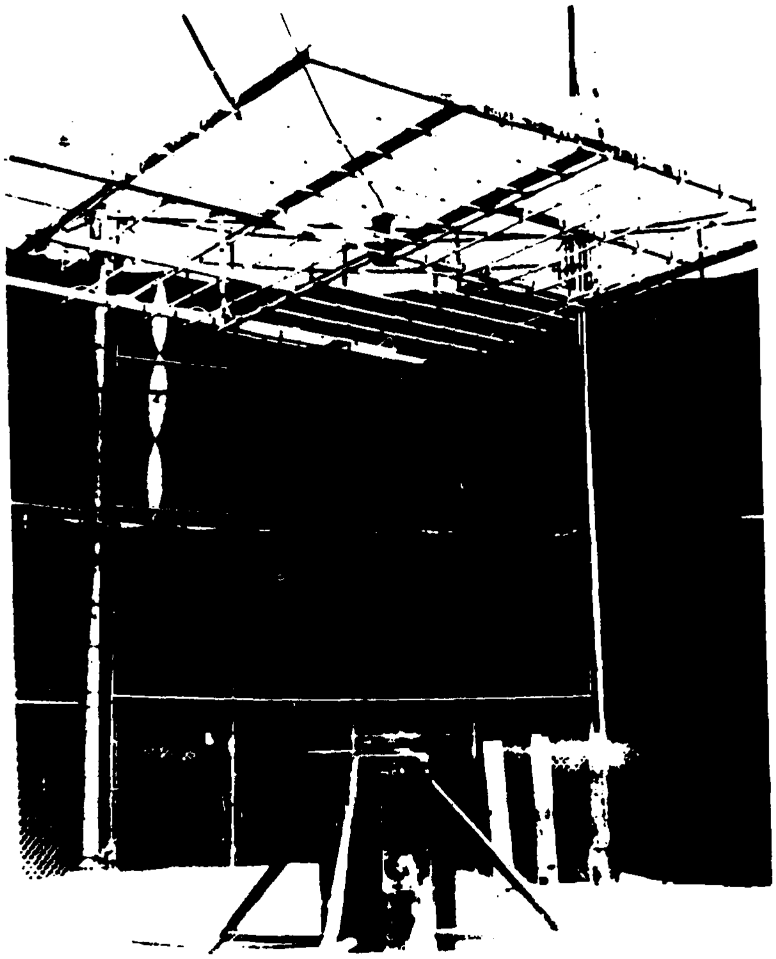


Figure 45. Rain test configuration.

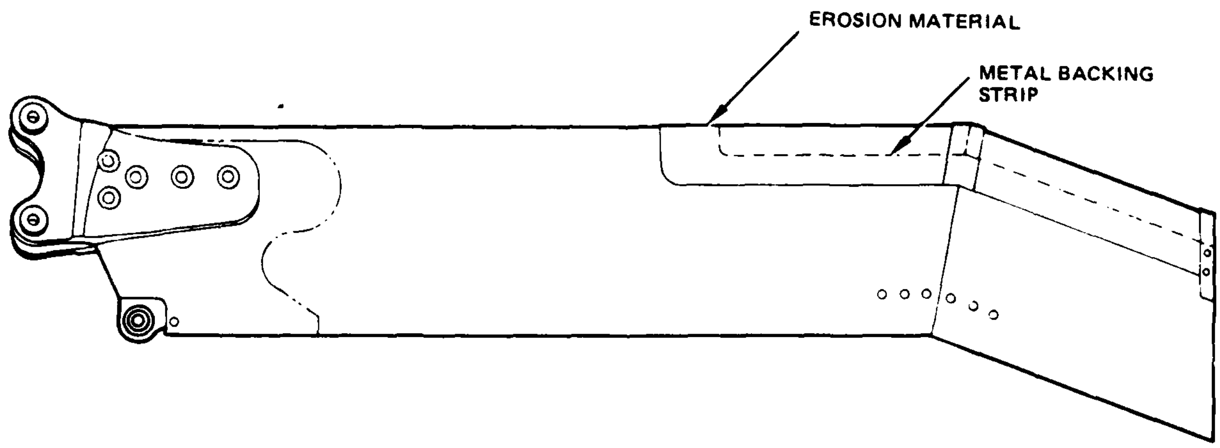


Figure 46. Erosion test specimen.

TABLE 9. EROSION TEST SUMMARY

Material	Specimen	Time/Minutes	Conditions
Dunlop	1	20	Slight pitting
		65	Bond separation, severe pitting, worn through (See Figure 63)
Stevens	1	20	Severe pitting
		30	Bond failure
	2	35	Slight pitting
		50	Severe pitting
		51	Bond failure
BF Goodrich	1	45	Slight tearing
		105	Small pinholes
		108	Severe abrasion
	2	95	Numerous small holes
		Repaired damage with kit	
		360	Minor abrasion

Note: All material 0.025 inch thick

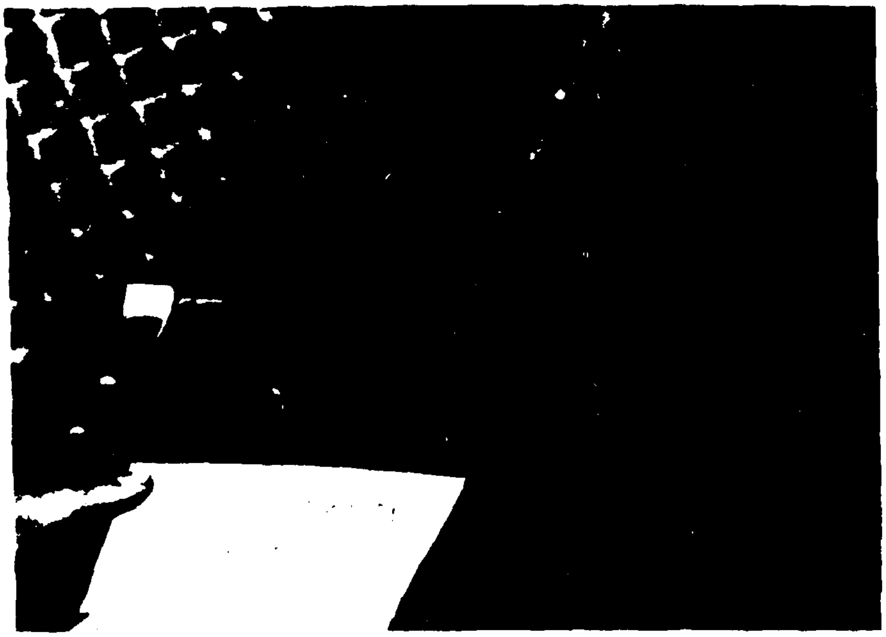


Figure 47. Dunlop material after 65 minutes.

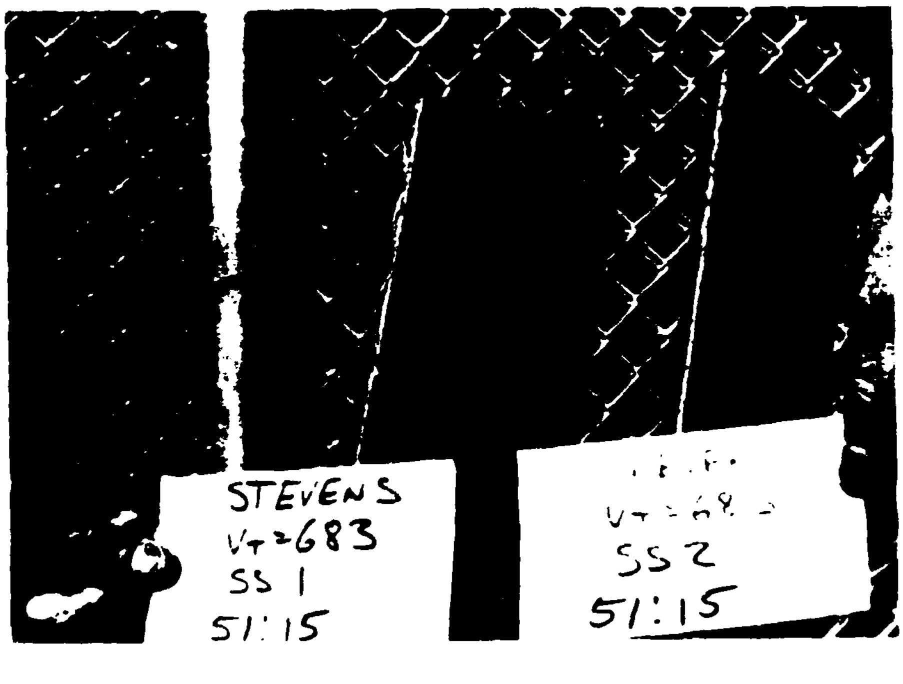


Figure 48. Stevens material after 51.25 minutes.

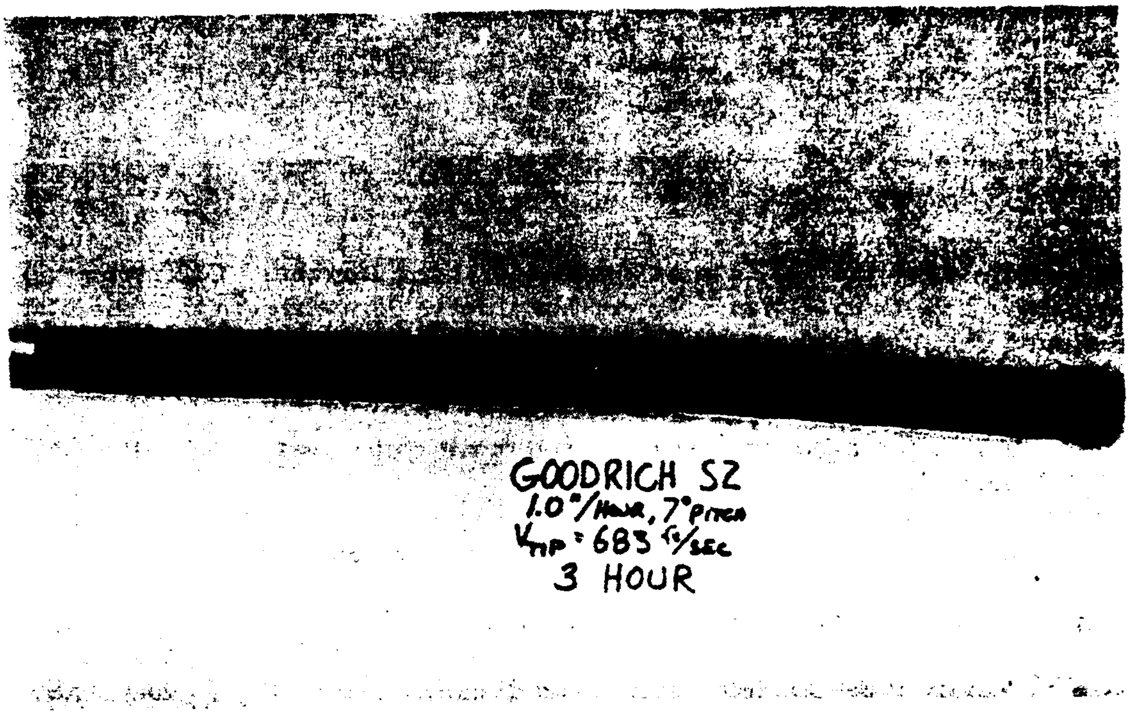


Figure 49. Goodrich material after 180 minutes with no repair.

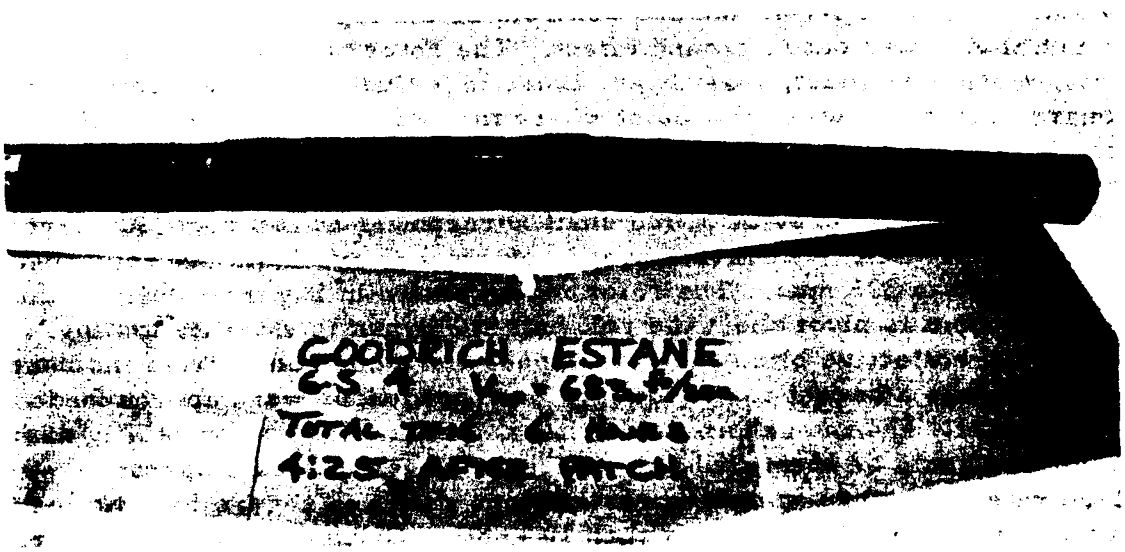


Figure 50. Goodrich material after 360 minutes with swept tip only repaired.

WHIRLSTAND TEST

The whirltest for the CMRB was conducted at the Lockheed California Company's Rye Canyon Whirl Tower Facility to demonstrate that the blade developed under the fabrication processes established by the MM&T program was satisfactory for flight. The objectives of the test were:

- Establish characteristics of the main rotor system with the CMRBs installed.
- Survey rotor and control system stresses and motions.
- Measure static thrust performance.
- Verify freedom from static and dynamic instability modes that are excitable on the whirlstand.
- Conduct a 50-hour endurance test in accordance with MIL-T-8679 (Reference 8).

Figures 51, 52, and 53 show one CMRB and how the set of them was mounted together with an AH-64A hub and controls on the top of the whirltower, high enough that it was out of ground effect. The rotor hub assembly upper controls, stationary mast, mast base, truss legs that support the rotor, and stationary controls down to the point where they connected to the whirltower's actuators were AH-64A flight hardware components. The whirltower had six synchronous electric motors with variable-frequency control to drive the rotor. They could provide 3,700 shaft horsepower at 289 rpm (100 percent N_r for the AH-64A). Accurate speed control was available over the speed range of 260 to 376 rpm. The rotor mount shown in Figure 54 allows the rotor freedom to pivot about the roll axis for dynamic stability testing. Cyclic and collective pitch and rotor speed were controlled from the control room that was adjacent to the tower. Test conditions were approached incrementally and in such an order that any hazardous or potentially damaging conditions could be identified immediately. A guide to safe operation was the blade retention strap operating restrictions shown in Figure 55. No testing was conducted in winds greater than 10 knots. Critical parameters were monitored in real time by the test crew while automatic monitoring devices provided warning of incipient overload conditions and could actuate stick-centering or power shutdown as necessary. A visual inspection of the rotor and controls was made routinely, and also after each overspeed run $\geq 1.25N_r$) or after five minutes operation outside the boundaries of Figure 55.

[8] Military Specification - TEST REQUIREMENTS, GROUND, HELICOPTER, MIL-T-8679, 5 March 1954.

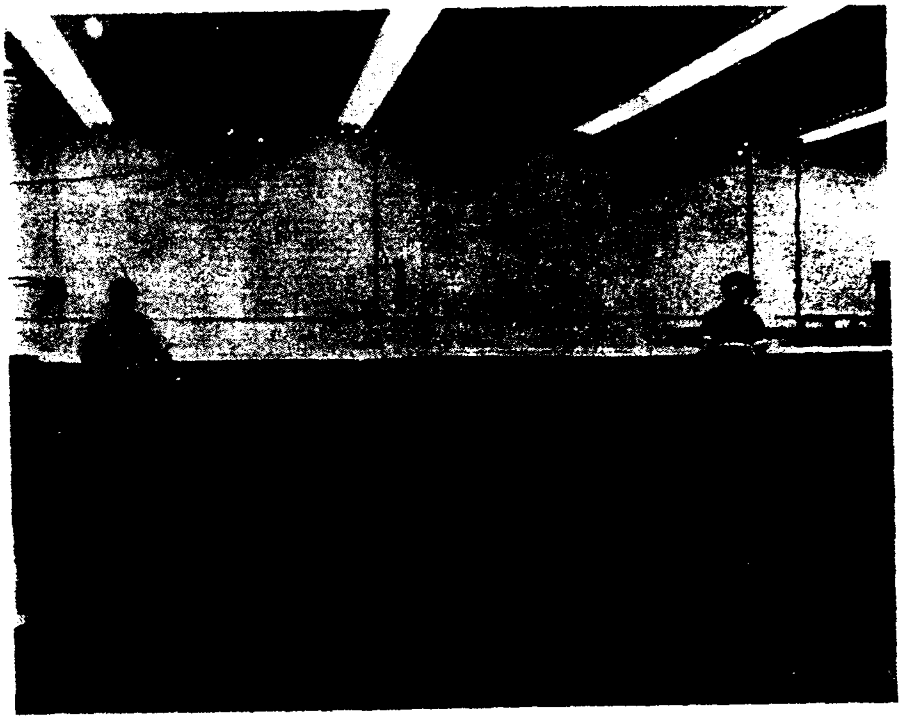


Figure 51. CMRB for whirlstand test.

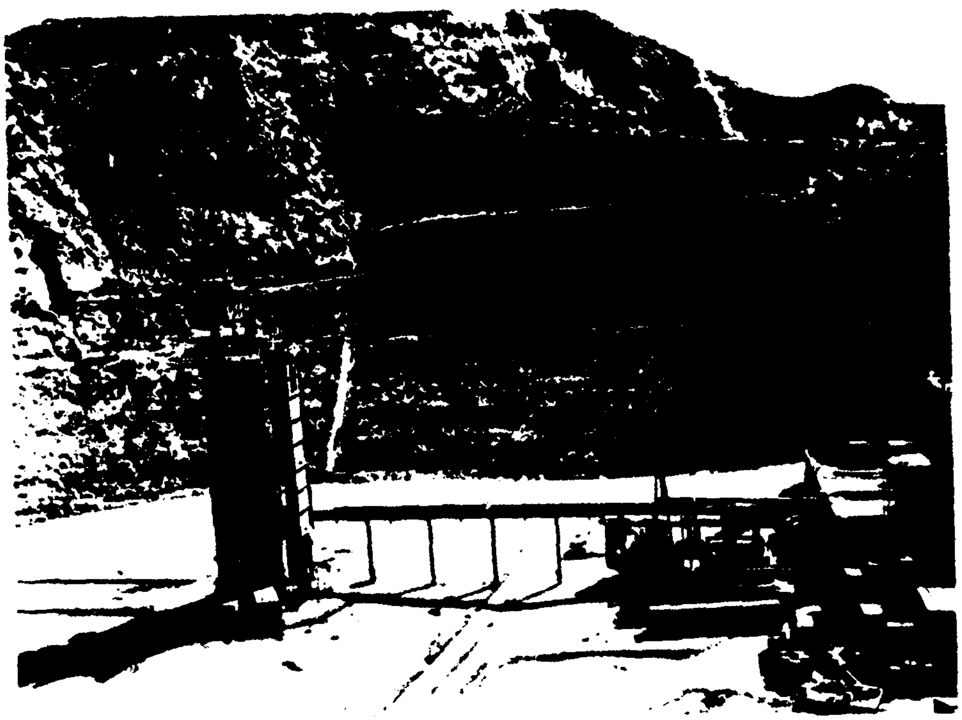


Figure 52. Whirl tower and bowl.

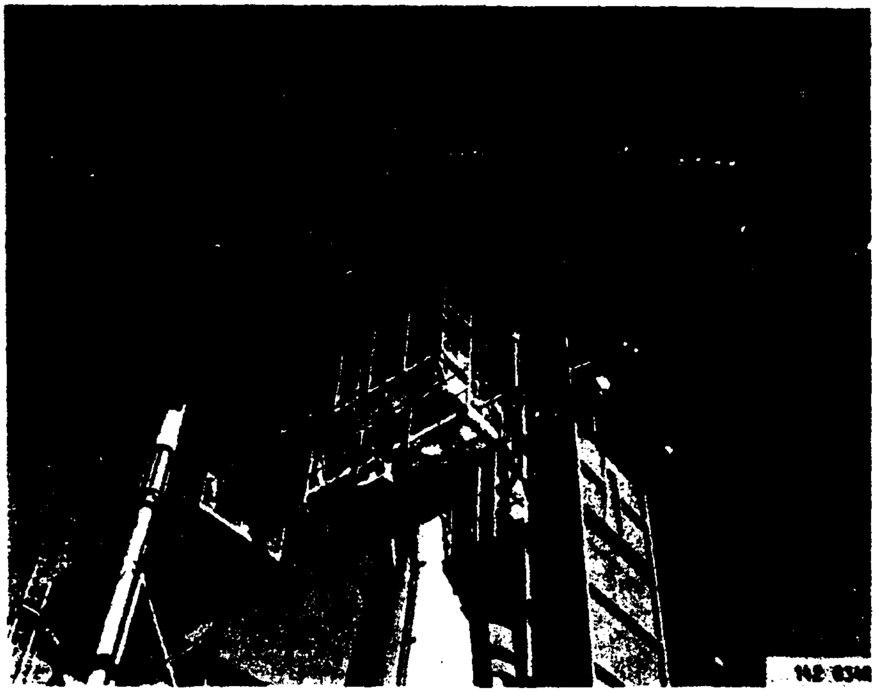


Figure 53. Main rotor as viewed from ground level.

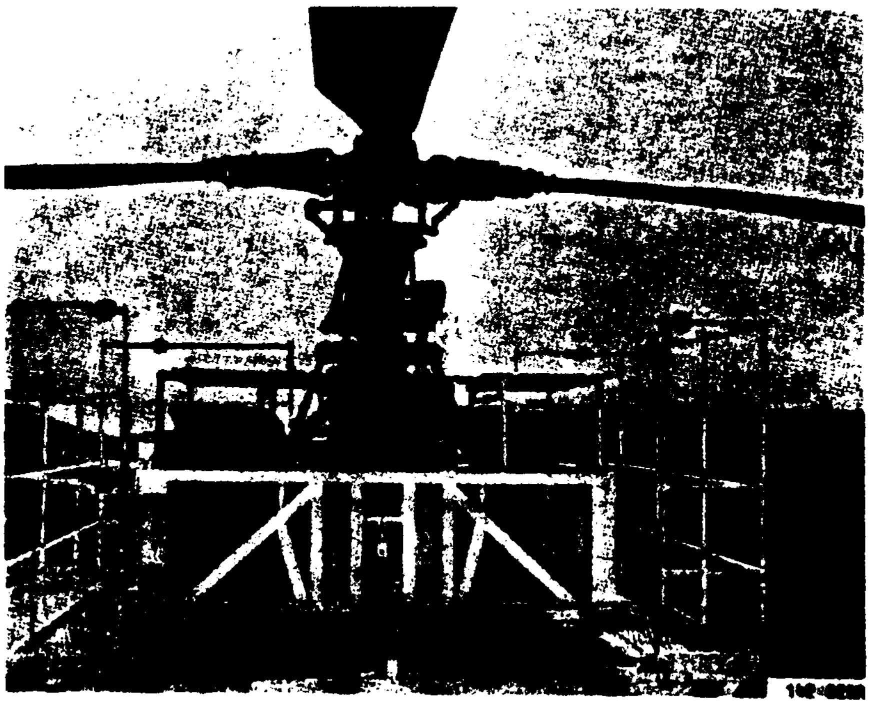


Figure 54. Rotor and control system installed on Lockheed whirl tower inertial frame.

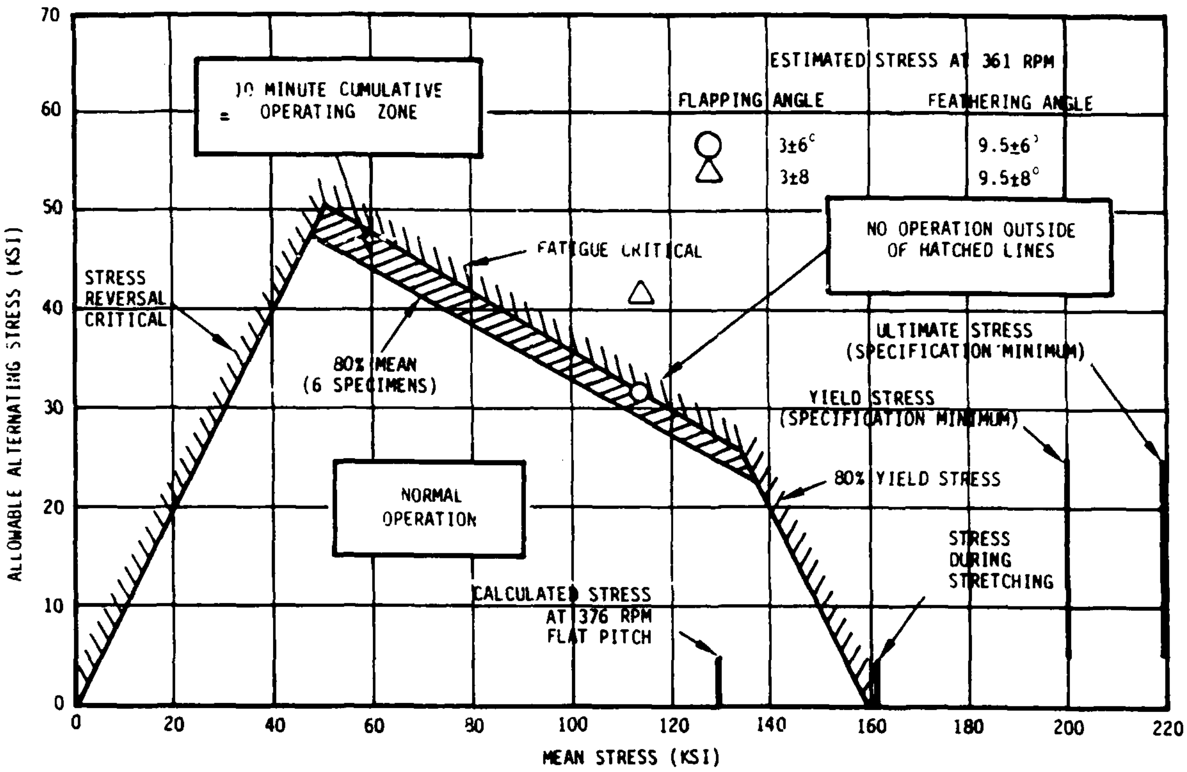


Figure 55. Main rotor strap operating restrictions.

The loads and motions that were measured are listed in Table 10. All rotor and control system components that required strain gaging were instrumented at HHI's Culver City Facility and were calibrated in its Structures Laboratory prior to installation on the whirl tower. System checkout calibrations were conducted after the rotor system was assembled on the tower. Output signals from rotating measurements were passed through the existing Lockheed slip ring assembly to the nonrotating system. In the control room, all signals were displayed on an oscillograph using daylight developing paper for quick readout. Selected parameters were routed to display oscilloscopes on the controller's panel. These scopes were marked to indicate limit values. Provision was made to link any of the recorded signals to Rye Canyon Data Central where the signals were recorded and could be processed in near-real-time by the computer facility. Control of computer processing was available from a terminal in the tower control room, and computer output was displayed on a cathode ray tube.

TABLE 10. LIST OF INSTRUMENTATION

Parameter	Rotor Station (in.)	Frequency Response (Hz)	Limit Range
Blade No. 1			
Flapwise bending moment	46	50	±40k in. -lb
Flapwise bending moment	174	50	26k ±39 in. -lb
Flapwise bending moment	260	50	13k ±19k in. -lb
Chordwise bending moment	103	50	44k ±85k in. -lb
Blade torsion moment	104.5	50	7k ±14k in. -lb
Lead-lag damper load, trailing edge	19	50	9k ±8k lb
Pitch link load	--	50	-1k ±2k lb
Flapping angle at feathering bearing	11	10	-6 to +23 deg
Feathering angle at feathering bearing	11	10	-31.6 to 33.6 deg
Lead-lag angle at lead-lag pin	34.5	10	+7.5 to -3.5 deg
Lead-lag link flapwise bending	34.0	50	±40k in. -lb
Main rotor strap stress**	--	50	See Figure 1
Blade No. 2			
Flapwise bending moment	46	50	±40k in. -lb
Pitch link load	--	50	-1k ±2k lb
Main rotor strap stress**	--	50	See Figure 1
Blade No. 3			
Main rotor strap stress**	--	50	See Figure 1
Pitch link load	--	50	-1k ±2k lb
Blade No. 4			
Main rotor strap stress**	--	50	See Figure 1
Pitch link load	--	50	-1k ±2k lb
Main Rotor Truss Leg***	--	50	±35k lb
Drive shaft torsion	--	50	600k ±150k in. -lb
Mast bending moment			
Lateral	--	50	440k in. -lb
Longitudinal	--	50	440k in. -lb
Actuator loads			
Longitudinal	--	50	±4000 lb
Lateral	--	50	±1220 lb
Collective	--	50	±5600 lb
Collective actuator input position	--	10	
Pitch actuator input position	--	10	
Roll actuator input position	--	10	
Tower lift	--	50	
Tower pitch moment	--	50	
Tower roll moment	--	50	
Tower gimbal roll angle	--	50	
Rotor index pip	--	50	40 to 376 rpm
Pressure altitude*	--	--	500 to 4000 ft
Outside air temperature*	--	--	30° to 120° F
Wind speed*	--	--	0 to 20 kn
10-Hz timing signal	--	50	

* Visual readings recorded on test data sheet.
** Four gages total per strap assembly.
*** Eight legs to be instrumented.

Whirl testing of the CMRB was accomplished in a total of 92.9 hours with data collected for the following test conditions:

- Main Rotor Track and Balance
- Natural Frequency Survey
- Rotor Stability Investigation
- Stress and Motion Survey
- Endurance Test
- Out of Ground Effect (OGE) Performance

These tests are summarized in Table 11.

The CMRB whirl test included three blade configurations, Standard, Mod 1, and Mod 2 that are described in Table 12.

Initial composite blade whirl tests indicated that the standard composite blades had a less rigid trailing edge structure than the metal blades. This conclusion was supported by higher torsional load data at blade Station 104, and a loss of lift with increased rpm for a constant collective position. CMRB track also degraded at the higher rpm's. Deformation of the blade airfoil section was considered to be the prime cause of these effects. The Mod 1 and Mod 2 blade configurations resulted from efforts to stiffen the trailing edge and lower the torsional loading. These modifications reduced the loss of lift, improved blade track at high rpm, and lowered the torsion loading. Even with this stiffening, the characteristics of the CMRB did not completely duplicate those of the metal blades. No conclusions were drawn from a comparison of these characteristics. It was considered that the loading characteristics were unique to each composite and metal blade design.

An excellent rotor system balance of 0.06 ips at 250 rpm was achieved with little difficulty during run 18. The standard 100 percent N_r (289 rpm) was not used for balance data point because of lateral rotor/tower resonant peaks at 288 rpm and approximately 320 rpm. Overspeed data confirmed these peaks as well as a rotor/tower vertical resonance at approximately 340 rpm. These resonances are unique only to the whirl tower installation. Although the Mod 1 and Mod 2 changes degraded the rotor balance slightly, no further attempts were made to balance the blades. The balance remained between 0.1 to 0.2 ips at 250 rpm throughout the Mod changes. Tracking the CMRB's at 289 rpm was accomplished by adjusting the main rotor pitch links. Trailing

TABLE 11. WHIRL TOWER TEST LOG

Run	Date	Run Time (hour)	Cumulative Time (hours)	Purpose	Comments
17 (Initial Run)	2-25-80	1.6	1.6	Main Rotor Track and Balance	Composite blades installed. Track ok. Balanced to 0.3 ips at 250 rpm.
18	2-26-80	1.6	3.2	Main Rotor Track and Balance	Achieved 0.06 ips at 250 rpm. Tracked to 346 rpm.
19	2-27-80	1.6	4.8	Natural Frequency Survey Rotor Stability Investigation	Completed natural frequency survey. Achieved 376 rpm flat pitch.
20	2-28-80	1.5	6.3	Rotor Stability Investigation	0.02 damping at 376 rpm, -5 collective; 0.04 damping at 366 rpm. -6.3 collective.
21	2-29-80	2.0	8.3	Rotor Stability Investigation Natural Frequency Survey	Stability documented below 350 rpm. White noise additional natural frequency data.
22	3-3-80	1.3	9.6	Rotor Stability Investigation Natural Frequency Survey	Stability data to 361 rpm documented; white noise additional natural frequency data.
23	3-4-80	0.5	10.1	Stress and Motion Survey	Auto shutdown due to tower drive motor failure.
24	4-12-80	0.3	10.4	Drive Motor Synch	Electrical phase data for planetary drive motor synch.
25	4-14-80	1.7	12.1	Drive Motor Synch	Electrical phase data for planetary drive motor synch.
26	4-15-80	3.2	15.3	Stress and Motion Survey	Completed 140 data points for stress and motion survey. Auto shutdown due to tower drive motor failure.
27	4-18-80	2.7	18.0	Stress and Motion Survey Natural Frequency Survey	Completed 100 data points for stress and motion survey. Additional natural frequency data.
28	4-19-80	3.7	21.7	Endurance Test	Completed endurance specification hours 1, 2, and 3.
29	4-21-80	2.5	24.2	Endurance Test	Completed endurance specification hours 4 and 5.
30	4-22-80	1.1	25.3	Rotor Stability Investigation	Completed rotor stability requirements to 375 rpm.
31	4-23-80	4.7	30.0	Endurance Test	Completed endurance specification hours 6, 7, 8, and 9.
32	4-24-80	1.1	31.1	Endurance Test	Completed endurance specification hour 10.

TABLE 11. WHIRL TOWER TEST LOG (CONT)

Run	Date	Run Time (hour)	Cumulative Time (hours)	Purpose	Comments
33	5-17-80	2.1	33.2	Track and Balance Rotor Stability Investigation	Blades Mod 1. Track improved with change in overspeed rpm. Completed collective power sweep. Achieved 371 rpm flat pitch.
34	5-19-80	2.5	35.7	Rotor Stability Investigation	Completed stability investigation.
35	5-21-80	3.4	39.1	Endurance Test	Completed endurance specification time to 12.8 hours.
36	5-22-80	5.0	44.1	Endurance Test	Completed endurance specification time to 16.9 hours.
37	5-23-80	3.0	47.1	Endurance Test	Completed endurance specification time to 19.3 hours.
38	5-27-80	5.1	52.2	Endurance Test	Completed endurance specification time to 23.3 hours.
39	5-28-80	4.1	56.3	Endurance Test	Completed endurance specification time to 26.6 hours.
40	5-29-80	4.2	60.5	Endurance Test	Completed endurance specification time to 30.0 hours.
41	5-30-80	2.8	63.3	Endurance Test	Completed endurance specification time to 32.3 hours.
42	6-17-80 6-18-80	3.2	66.5	Main Rotor Track and Balance Rotor Stability Investigation	Mod 2 on blades. Track with rpm improved. $\theta_{3/4}$ = 0 degrees and 4 degrees Stability data.
43	6-19-80	2.4	68.9	Rotor Stability Investigation	Completed stability investigation in Mod 2 configuration. Standard Tip Weights $\theta_{3/4}$ = 2 degrees, 6 degrees, 8 degrees stability data.
44	6-20-80	3.9	72.8	Endurance Test	Completed endurance specification time to 35.4 hours.
45	6-21-80	4.3	77.1	Endurance Test	Completed endurance specification time to 39.0 hours.
46	6-23-80	1.1	78.2	Drive Motor Synch	Electrical phase data for planetary drive motor synch.
47	6-24-80	4.5	82.7	Drive Motor Synch Endurance Test	Removed No. 6 tower drive motor. Completed endurance specification time to 41.9 hours.
48	6-25-80	6.3	89.0	Endurance Test	Completed endurance specification time to 47.4 hours.
49	6-26-80	3.1	92.1	Endurance Test	Completed endurance specification time to 50.0 hours.
50	6-27-80	0.8	92.9	Rotor Stability Investigation	Auto shutdown due to tower drive motor failure. Blade at Aft Tip Weight configuration.

TOTAL RUN TIME: 92.9 Hours

TABLE 12. BLADE CONFIGURATION

Run No.	Configuration	Description
17 through 32	Standard	Standard Configuration per B/P-311412500
33 through 41	Mod 1	Mod 1 configuration which consisted of the B/P-311412500 configuration plus graphite chordwise trailing edge stiffeners located between blade stations 201 and 264, upper and lower surfaces.
42 through 50	Mod 2	Mod 2 configuration which consisted of the Mod 1 configuration plus additional graphite chordwise stiffeners located at the blade sweep tip between blades stations 264 and TIP, upper and lower surfaces.

edge tab adjustments were not made because the whirl tower composite blades did not have adjustable tabs. The standard composite blades ran considerably out of track at the higher rpms. The Mod 2 blades tracked comparably to the metal blades at the higher rpm, showing that the Mod 2 configuration had solved the initial high rpm out-of-track problems.

Analytically predicted natural frequencies were checked with the blade in flat pitch and the rotor speed varied from 0.23 to 1.00 N_r. Discrete frequency excitations were input through the collective control system while spectral analyses of blade bending and torsion responses were obtained from the Data Central computer. Blade response variations with rotor speed showed two crossovers of rotor speed harmonics and blade natural frequencies. Second flap bending crossed 5/rev at 0.80 N_r and collective first chord bending crossed 4/rev at 0.93 N_r. See Figure 56. The blade torsional response to rotor speed showed no consistent trend. A cyclic mode survey was conducted to establish crossover points as the rotor speed was run up to 1.10 N_r at flat pitch. Crossover occurred for first flap bending with 3/rev at 0.46 N_r; second flap bending with 5/rev at 0.79 N_r; and first chord bending with 9/rev and 7/rev at 0.75 and 1.02 N_r. See Figure 57.

Rotor stability was investigated by increasing rpm and collective pitch in a stepwise manner with cyclic stick-stirring at each step. Automatic data processing provided near-real-time analysis of frequency and damping of the rotor system in response to the applied excitation. The effect of rotor

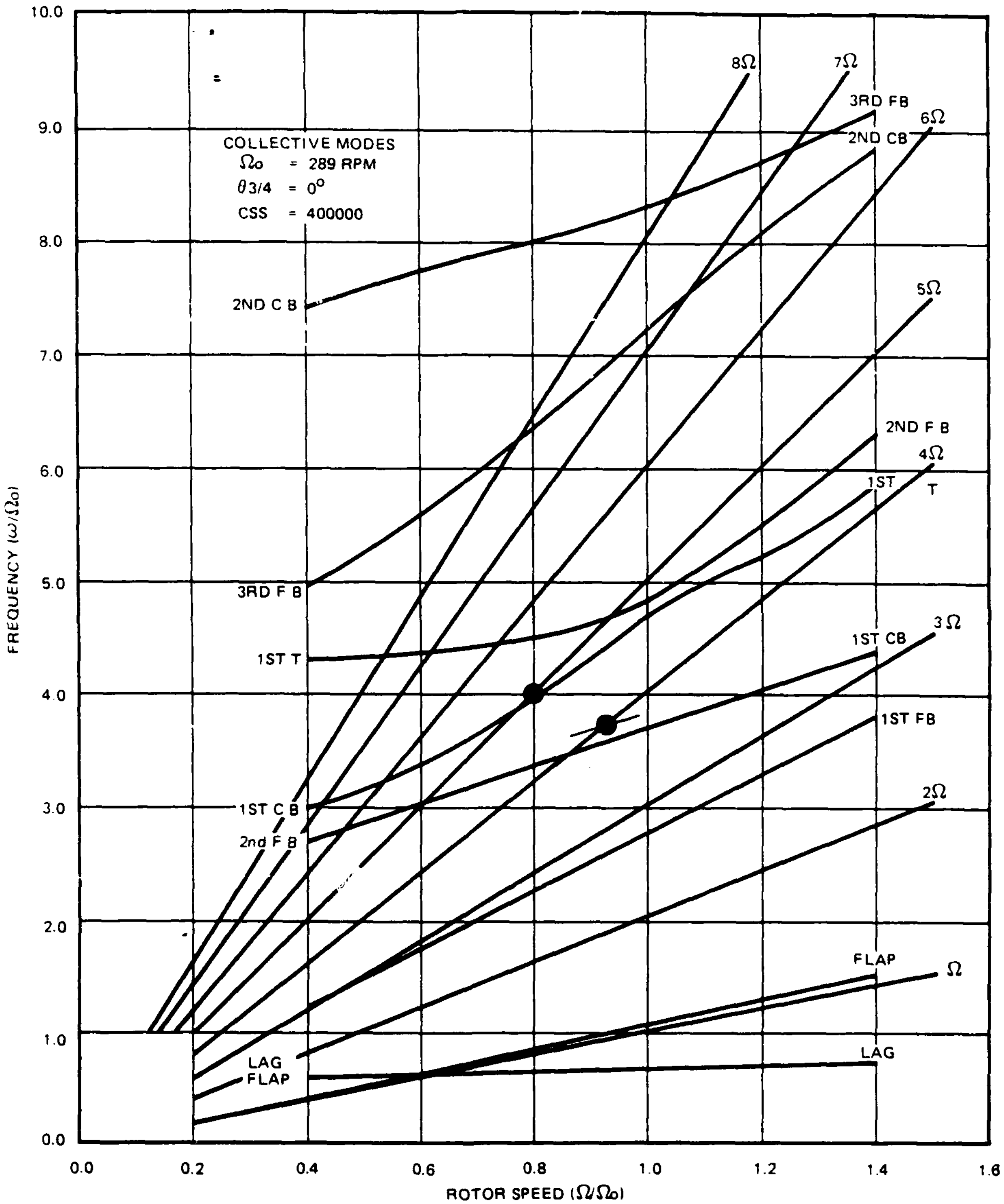


Figure 56. Composite main rotor blade resonance diagram, collective modes.

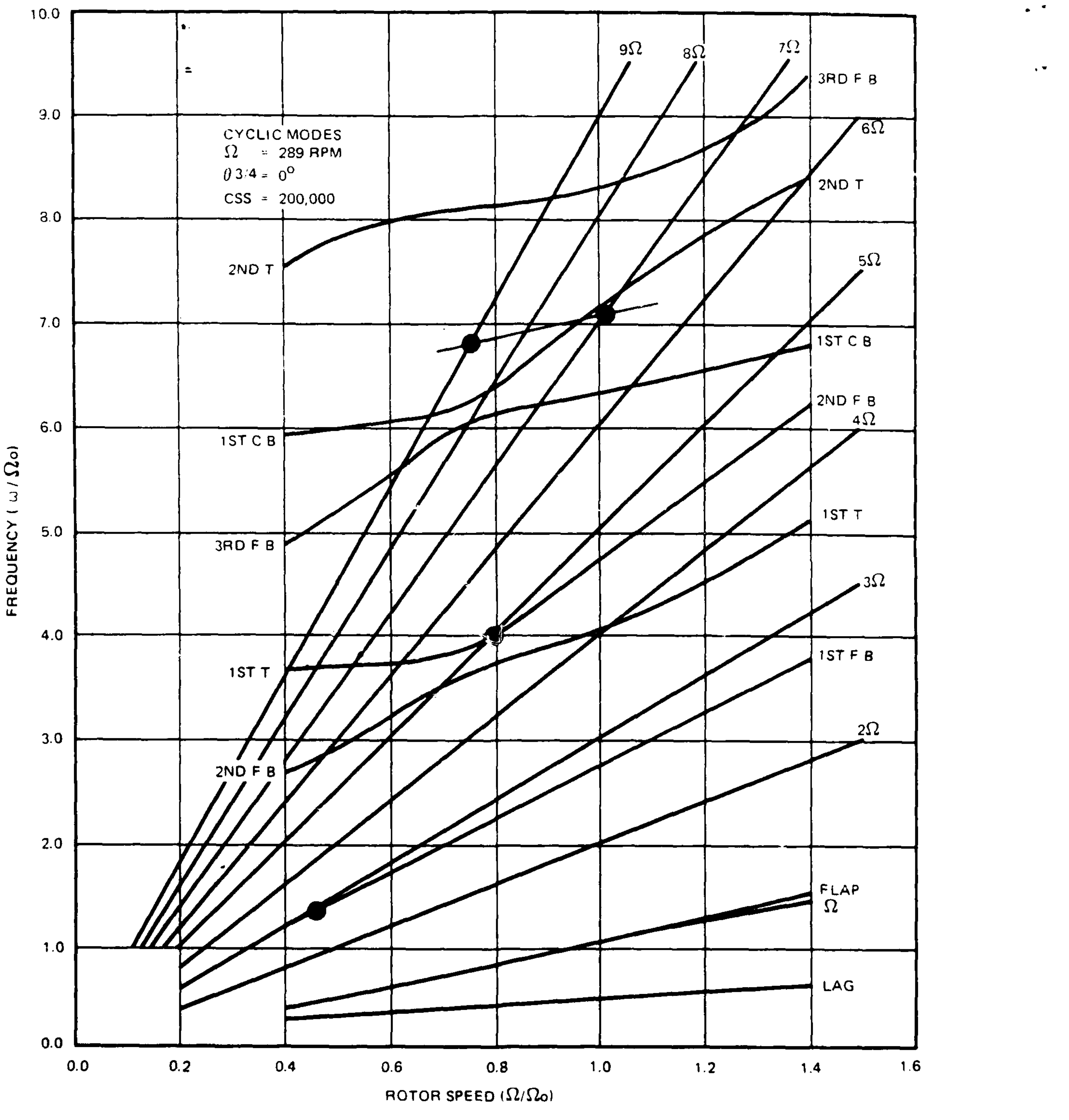


Figure 57. Composite main rotor blade resonance diagram, cyclic modes.

speed was investigated for collective pitch settings from zero to 8 degrees pitch. The minimum projected stability boundary occurred at 367 rpm (1.27 N_r) $\theta_{3/4}$ = 6 degrees with 2 degrees aft cyclic. See Figure 58. The Mod 1 and Mod 2 configurations had the same whirl mode stability boundaries within the scatter of the data.

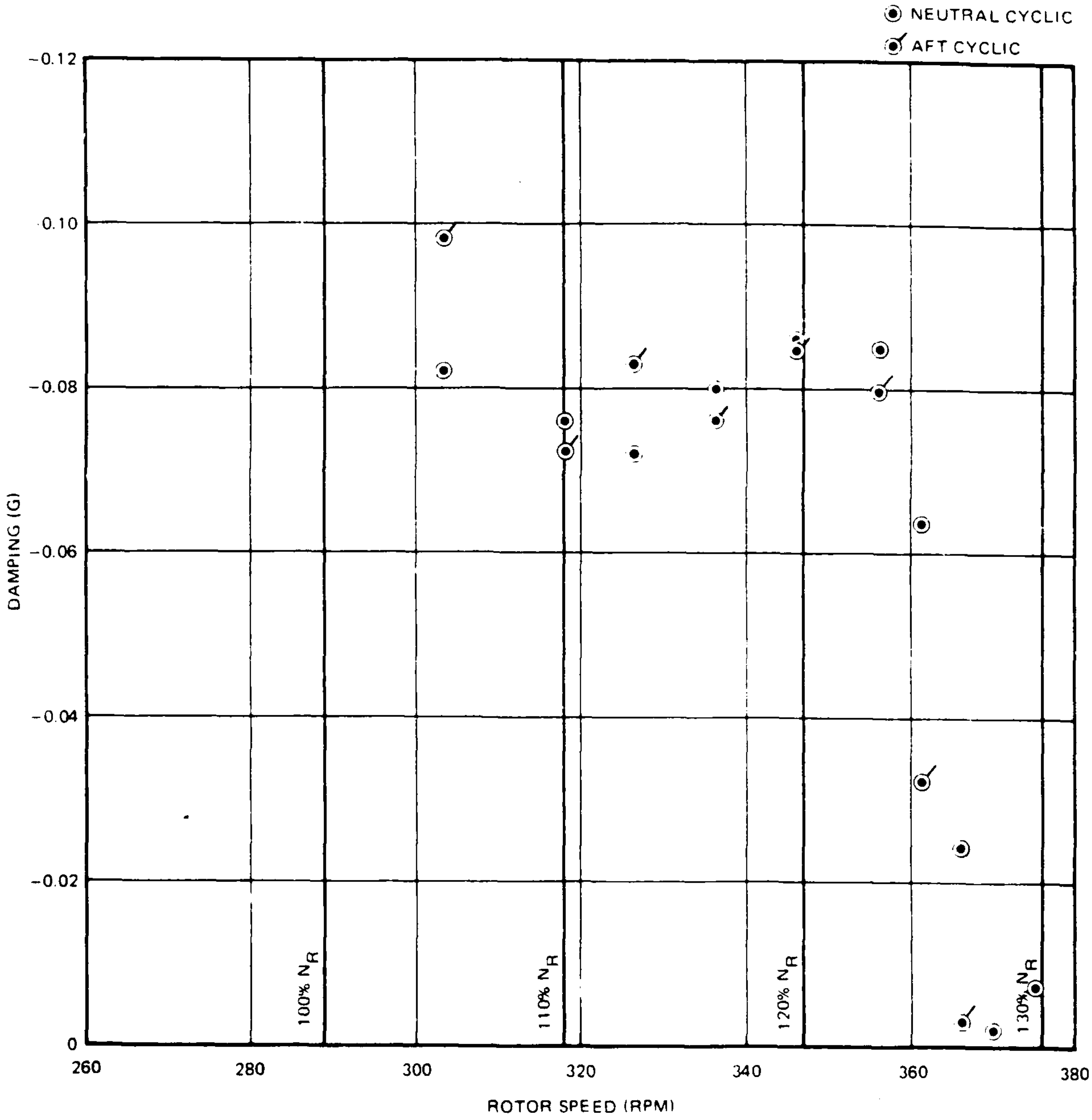


Figure 58. Whirl mode stability, gimbal fixed, $\theta_{3/4}$ = 6 degrees.

Instrumentation locations, component endurance limits, and maximum measured cyclic loads is shown in Table 13. In a stress and motion survey, it was found that, with the exception of the main rotor pitch housing station (BS 26) and main rotor mast, all of the measured cyclic loads were below the applicable endurance limits. The mast moment exceeded its endurance limit on a once per cyclic control input basis, not a once per rev basis. That is, the mast has one load cycle in going from zero cyclic to forward cyclic to aft cyclic and back to zero cyclic. With this type of loading frequency, the mast could tolerate over 30,000 control cyclings at the maximum measured moment of ±190,500 inch-pounds (197,000 inch-pounds aft to 184,000 inch-pounds forward cyclic). Given the relatively few number of cycles applied during the test program and the fact that most of the loads were less than the maximum, the fatigue damage to the mast was minimal. Strap loads stayed within the allowable boundaries as Figure 59 shows. None of the measured loads approached the allowable limit loads for any of the components.

The 50-hour endurance test was successfully completed to the rotor speed and power levels shown in Table 14, and as required by (Reference 8). A main rotor strap assembly (PN 7-211411146) was replaced after Run 41 when two of the strap laminates failed on the No. 4 blade position. This was a precautionary measure because of the extended overspeed runs conducted throughout the test program. During Mod 2 and prior to Run 42, a lower surface skin delamination was found on the No. 2 main rotor blade. It was concluded upon inspection that the skin in the center of the swept tip had debonded from two supporting internal stiffeners. The skin was rebonded to the stiffeners using a syringe, with soft aluminum rivets installed to prevent further delaminations.

Out of ground effect (OGE) performance data was measured from rotor lift and shaft torque data and is presented in terms of C_Q versus C_T and $\theta_{3/4}$ versus C_T in Figures 60 and 61. For comparison purposes, the whirlstand C_Q - C_T data for the CMRB and for the metal main rotor blades are shown in Figure 62. Performance data for the Standard, Mod 1 and Mod 2 CMRBs and the metal blade compare well in Figures 63 and 64.

TABLE 13. INSTRUMENTATION LOCATIONS, ENDURANCE LIMITS, AND CYCLIC LOADS

Component	Blade Station (in).	Load	Endurance Limit (in/lb)	Maximum Cyclic Load (in/lb)
Pitch	26.0	Flap Bending	14,880	16,000
Lead/Lag Fitting	34.5	Flap Bending	23,310	15,500
Blade	46.0	Flap Bending	10,890	5,500
Blade	174.0	Flap Bending	19,900	2,500
Blade	260.0	Flap Bending	21,100	2,500
Blade	103.0	Chord Bending	50,000	18,500
Blade	104.5	Torsion	8,000	1,250
Damper	-	Axial	2,990	2,500
Pitch Link	-	Axial	1,550	675
Stationary Mast	-	Bending	53,400 (single axis)	190,500
Longitudinal Actuator	-	Axial	2,062	500
Lateral Actuator	-	Axial	2,518	250
Collective Actuator	-	Axial	1,973	150

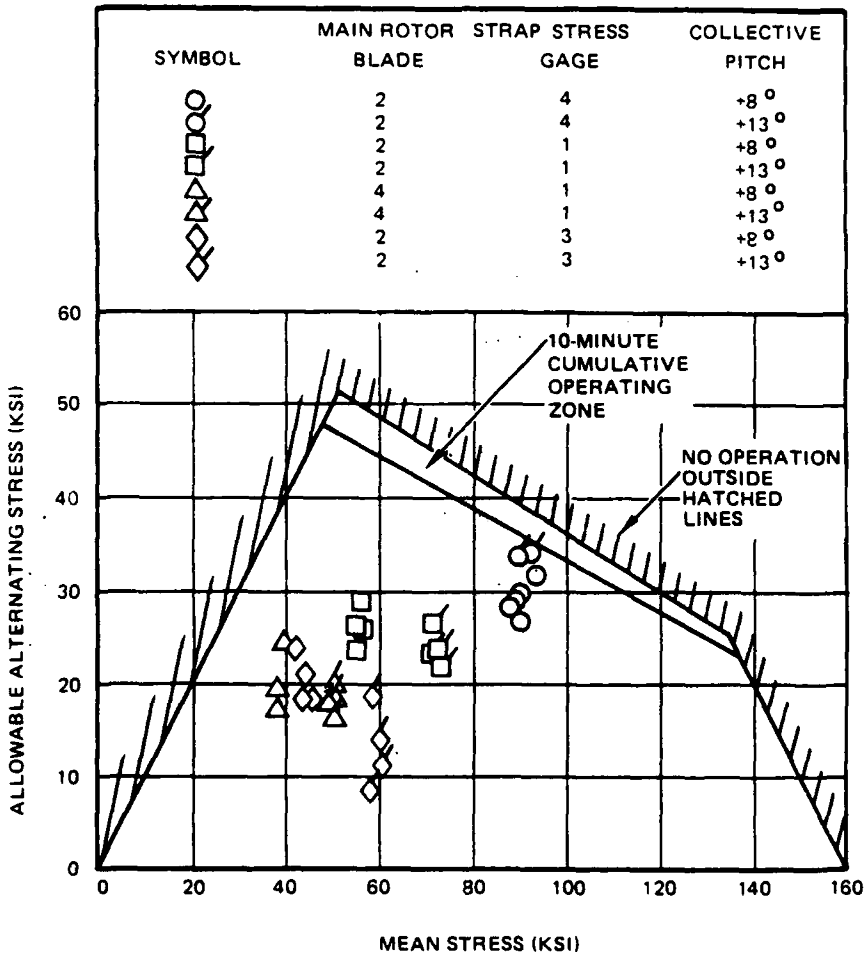


Figure 59. Strap stress cyclic load versus strap stress mean load at 289 rpm.

TABLE 14. ENDURANCE TEST SPEED AND POWER CONDITIONS

Condition	Rotor Speed (rpm)	Main Rotor Torque (ft-lb)	Main Rotor Power (shp)	Total Duration (hour)	MIL-T-8679 Paragraph
Intermediate power, design maximum power rotor speed (N_r) 4 degrees forward cyclic angle.	289	45,378	2497	7.5	3.4.2.2.4(a)(2)
Intermediate power, design maximum power-on rotor speed (N_r) 4 degrees forward cyclic angle.	289	42,943	2363	7.5	3.4.2.2.4(a)(2)
Intermediate power, 90 percent N_r, two-thirds longitudinal cyclic blade angle.** 4 degrees forward cyclic angle.	260	45,378	2246*	7.5	3.4.2.2.4(a)(3)
Intermediate power, 90 percent N_r, two-thirds longitudinal cyclic blade angle.** 4 degrees forward cyclic angle.	260	42,943	2126*	7.5	3.4.2.2.4(a)(3)
Intermediate power, 110 percent N_r, full longitudinal cyclic blade angle.** 4 degrees forward cyclic angle.	318	41,240	2497	7.5	3.4.2.2.4(a)(4)
Intermediate power, 110 percent N_r, full longitudinal cyclic blade angle.** 4 degrees forward cyclic angle.	318	39,027	2363	7.5	3.4.2.2.4(a)(4)
Intermediate power, 110 percent limit power-on rotor speed, one-third longitudinal cyclic blade angle.** 4 degrees forward cyclic angle.	361	37,811	2599	3.75	3.4.2.2.4(a)(5)
Intermediate power, 110 percent limit power-on rotor speed, one-third longitudinal cyclic blade angle.** 4 degrees forward cyclic angle.	361	39,965	2747	1.25	3.4.2.2.4(a)(5)
			TOTAL:	50.0	

*Torque limited.
**Or as limited by strap loading or stationary mast bending moments.

SYMBOL	PURPOSE	RPM	H_D	OAT	RUN NO.	POINT
○	COLLECTIVE SWEEP	289	1924 FT	65°F	19A	–
□	STRESS/MOTION SURVEY	289	2180 FT	69°F	26	56
◇	↓	289	↓	↓	↓	66
△		318				86
▷		318				105
◡		361				132

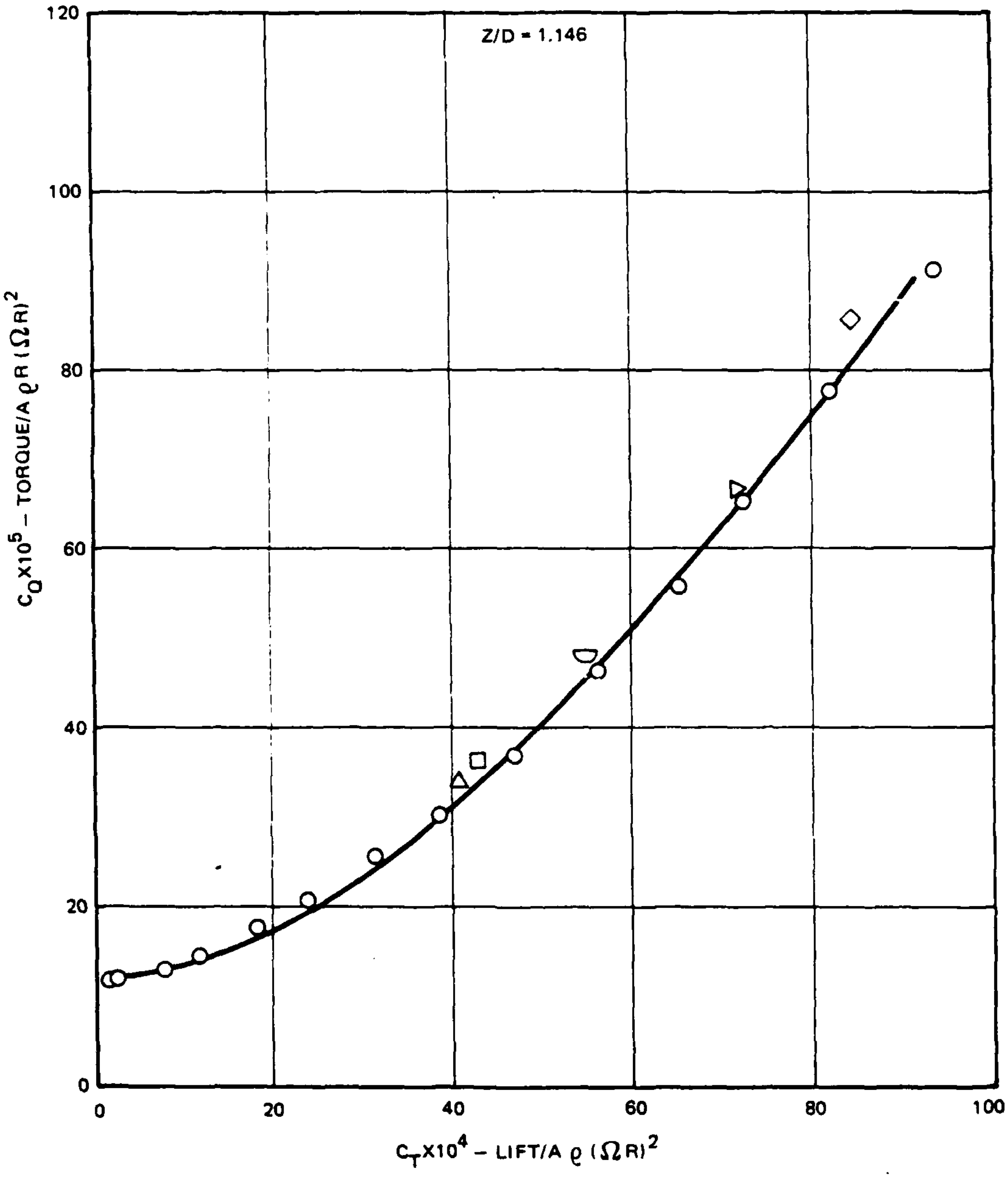


Figure 60. Torque coefficient versus thrust coefficient (standard CMRB configuration).

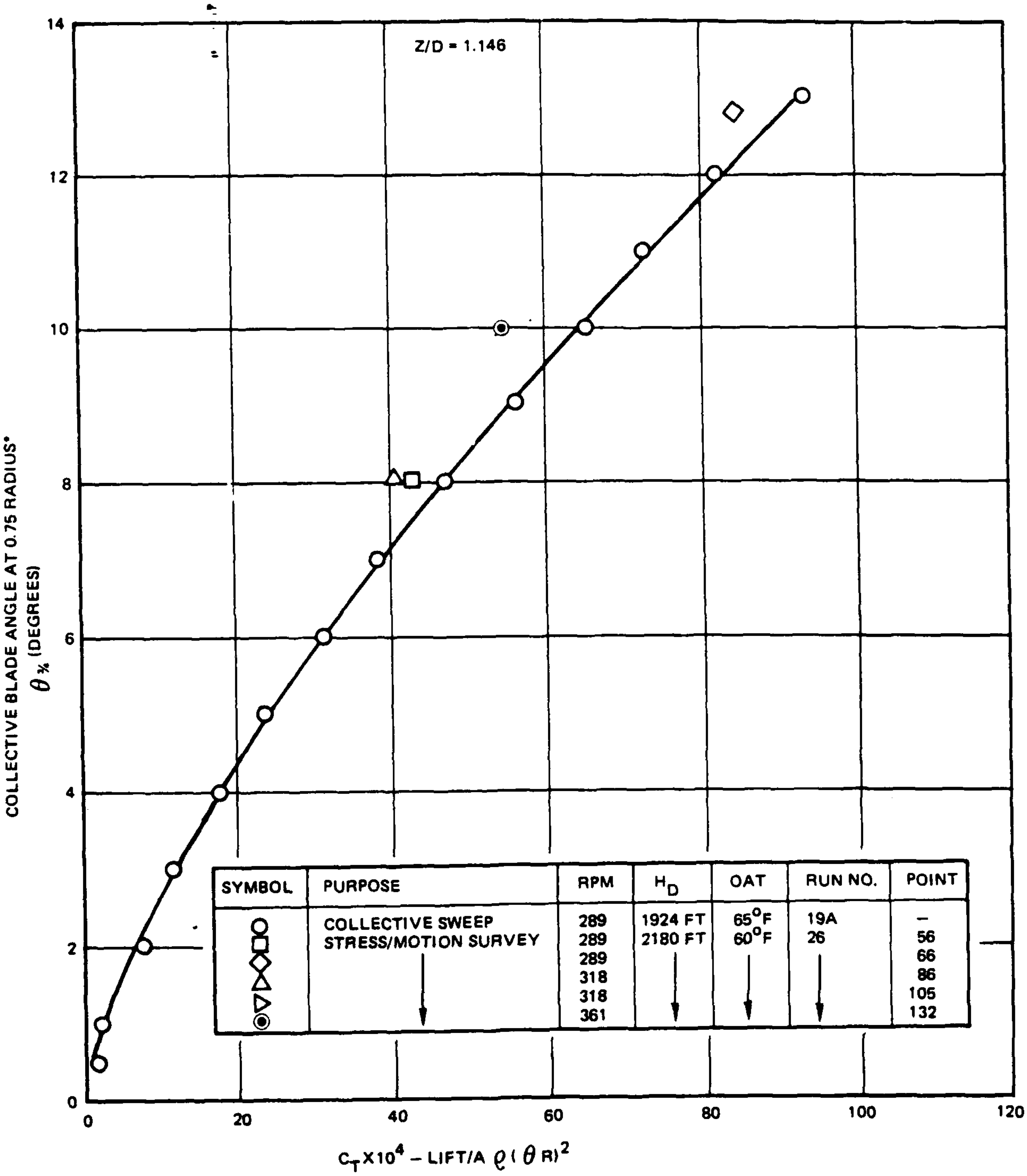


Figure 61. Blade collective pitch versus thrust coefficient (standard CMRB configuration).

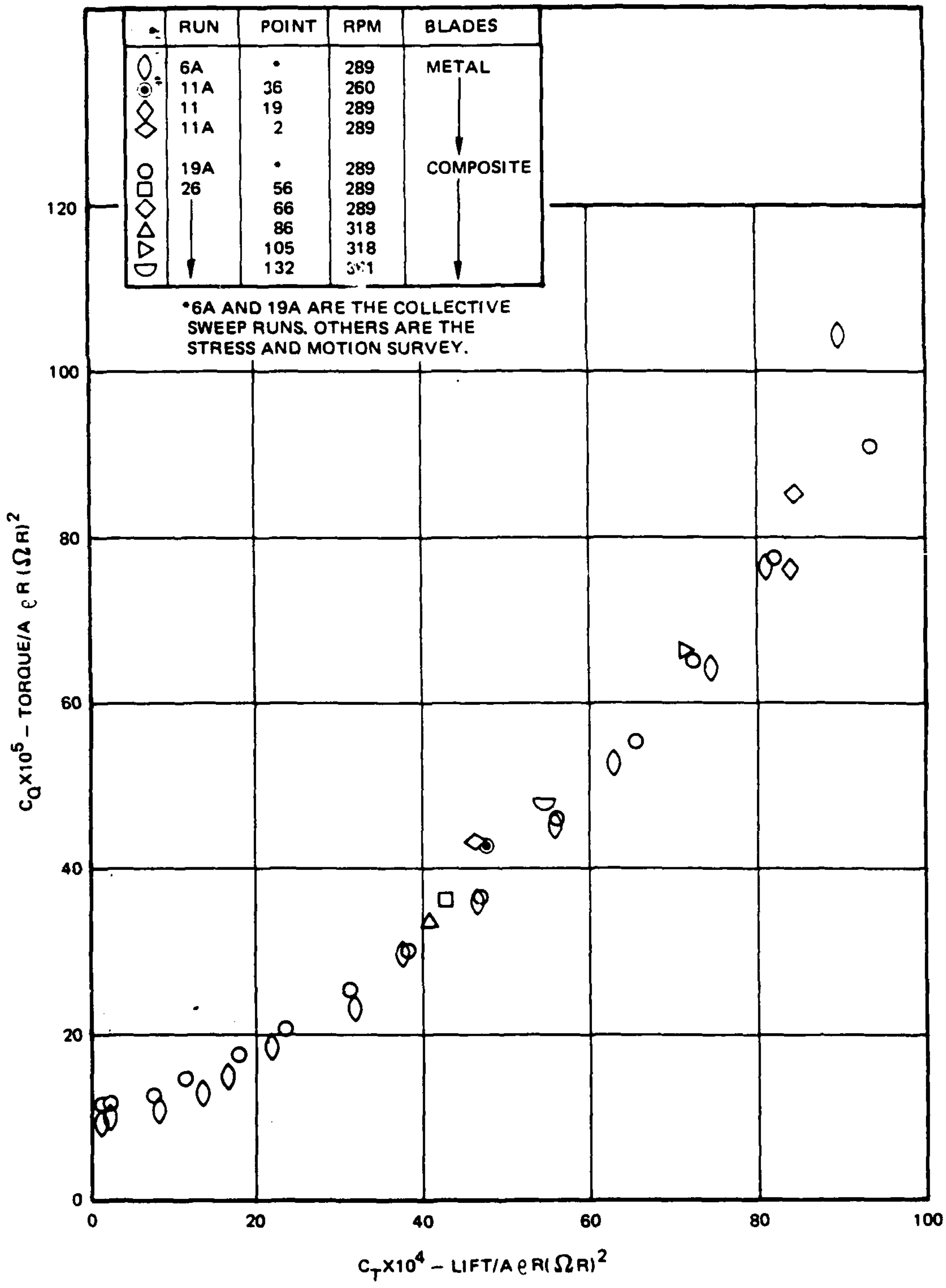


Figure 62. Torque coefficient versus thrust coefficient (metal and standard CMRB configuration).

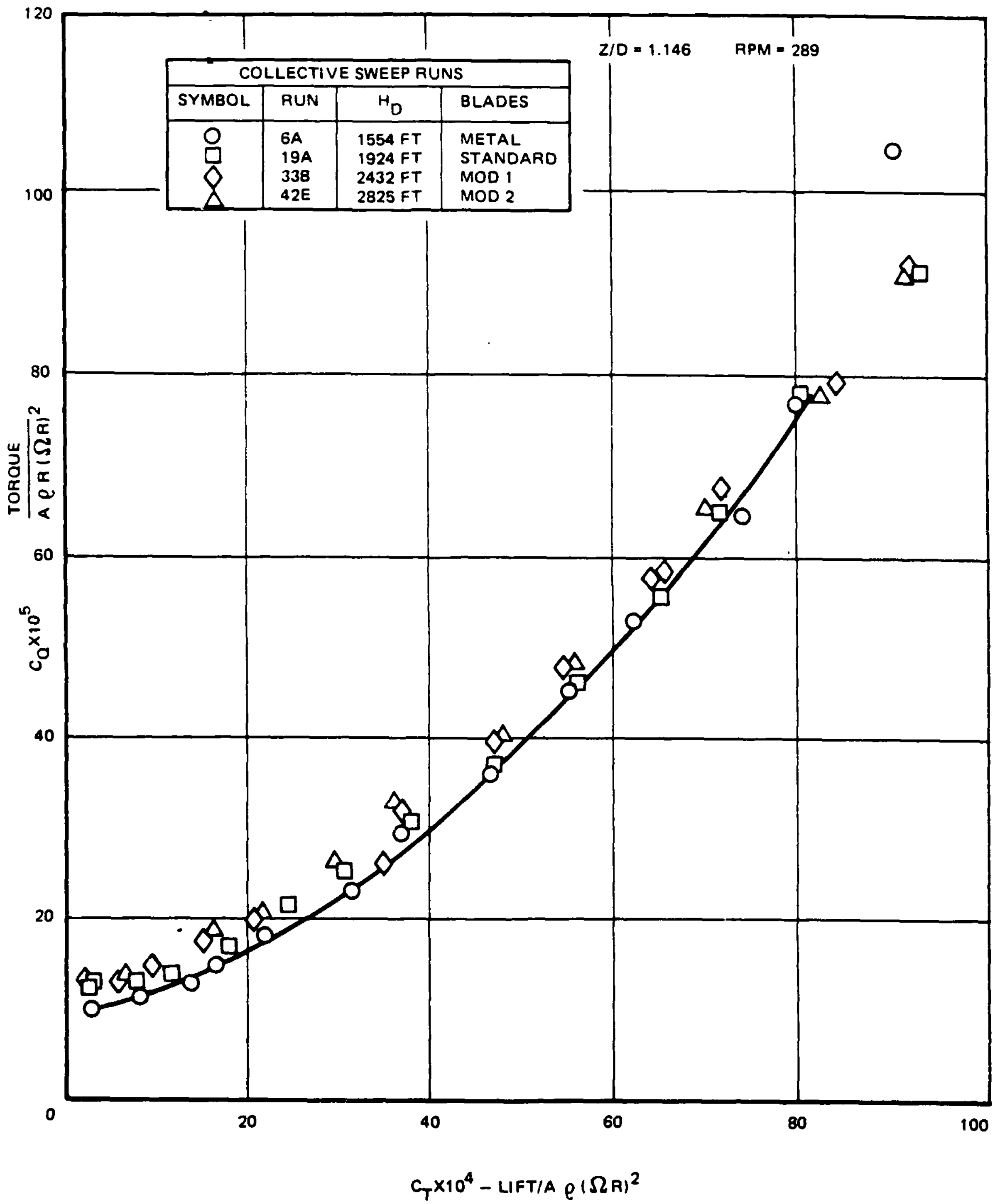


Figure 63. Torque coefficient versus thrust coefficient (metal and CMRB standard, mod 1, and mod 2 configurations).

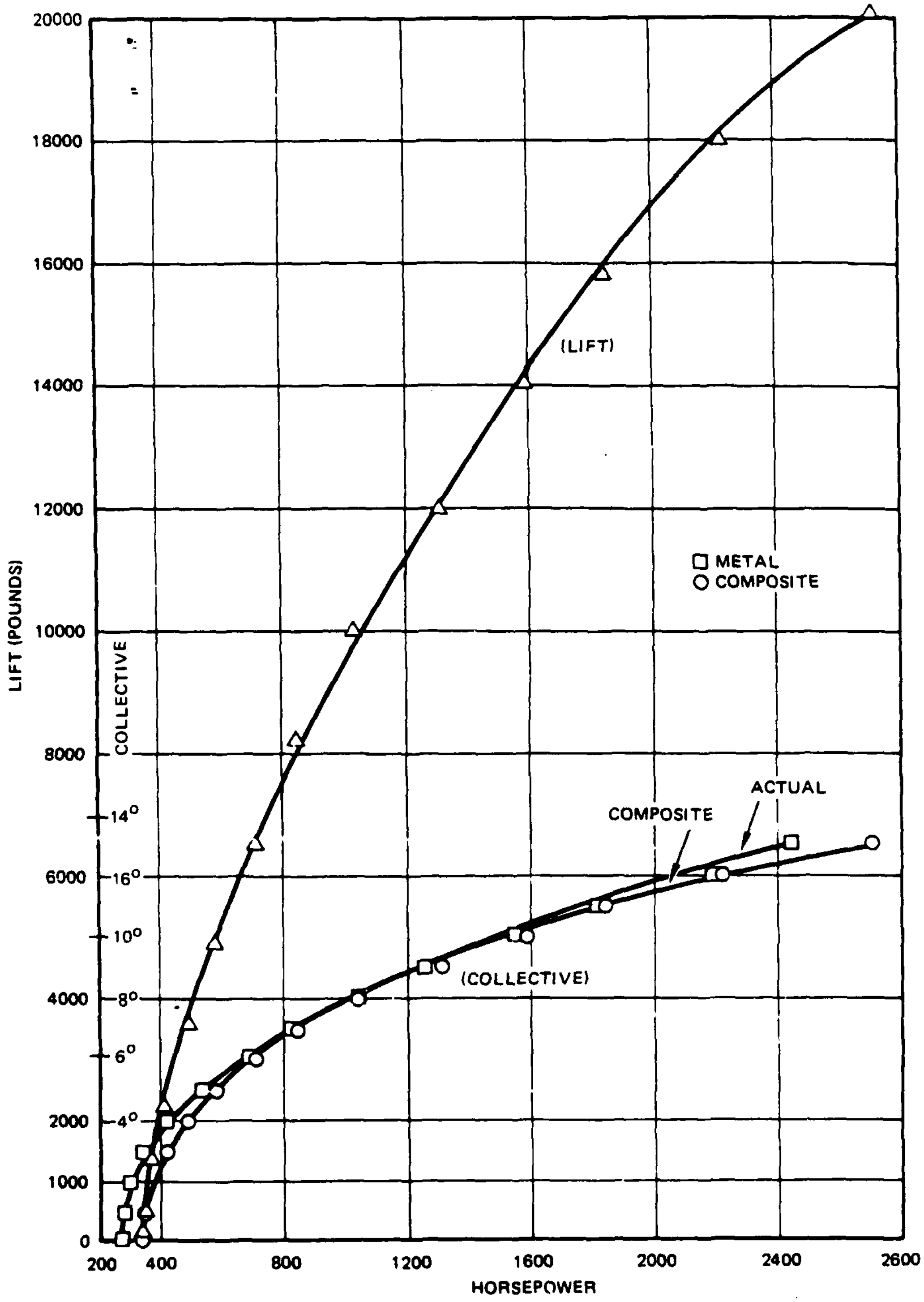


Figure 64. Collective power sweep at 289 rpm (100 percent N_r), composite main rotor blade.

DESIGN TO UNIT PRODUCTION COST

The determination of the design to unit production cost (DTUPC) is made in 1981 dollars. It is based on HHI's experience in fabricating primary structural components for its helicopters. The estimate for the CMRB is based on labor hours and on the cost of materials that HHI has experienced in fabricating rotor blades during the MM&T Program, and on process improvement factors that are accepted by the industry. While building CMRB S/N-1010, in the MM&T Program, a careful record of man-hours was accumulated as shown in Table 15. Tables 16 through 19 list the material used to make this blade. In estimating the DTUPC for the CMRB it is assumed that the first production blade (S/N-0001) will require the same number of man-hours as the S/N-1010 MM&T blade did, and that a 92 percent product improvement curve will be followed to production blade S/N-1000. All the rest of the 1,500 blades in a total assumed production run of 2,500 CMRBs will be fabricated for the same number of man-hours that were needed by S/N-1000. Figure 65 shows this man-hour schedule. It is further assumed that material cost for the S/N-1010 MM&T blade will be equalled by the S/N-0001 production blade and that material costs will follow the 98.5 percent improvement curve shown in Figure 66. The CMRB DTUPC is the sum of the cumulative average labor and material costs. Assuming a $35 per hour burdened labor rate:

Labor	=	$20,160
Material	=	8,138
DTUPC		$28,298 (1981 dollars)

The DTUPC value for the metal main rotor blade, as quoted by the HHI's AH-64A program office is $76,873. Compared with the metal blade, this DTUPC for the CMRB represents a saving of $48,575 (63 percent) per blade, or $121.4 million for 2,500 blades.

LIFE CYCLE COST SAVING (1981 DOLLARS)

The total saving that the CMRB promises over the life of the program is approximately $602 million relative to the metal main rotor blade for the AH-64A. It is calculated as follows:

Production Cost Saving	=	$48,575 x 2,500	=	$121,437,500
Life Cycle Cost Saving	=	4 x $121,437,500	=	+485,750,000
				607,187,500
MM&T Program			=	- 4,900,000
		Total Saving		$602,287,500

TABLE 15. CMRB FABRICATION MAN-HOURS

	Composites Laboratory	Other Fabrication	Manufacturing Engineering Planning Material Control
<u>Premade Parts for Blade Mold Cure</u>			
2530 Leading Edge Weight	25	-	
Tungsten WT, Etch and Prime	-	4	
CRES Rods, Etch and Prime	-	6	
2541 Wedge	10	-	
2542 Wedge	10	-	
2543 Core Tip	20	-	
2548 Fwd Tip	8	-	
Etch and Prime	-	6	
2549 Aft Tip	8	-	
Anodize	-	2	
2557 Root End Dam	16	-	
2563 Face Plate	20	-	
2567 Clevis Plate	20	-	
2568 Root End Bushings	30	-	
Heat Treat, Etch and Prime	-	10	
2547 Lightning Screen, MEK Clean	-	2	
2536 Trailing Edge Longo	24	-	
2572 Core, Aft	28	-	
2573 Channel	19	-	
2577 Fairing Strip	4	-	
Subtotal	242	30	70
<u>Non-Cured Wet Filament Wound Parts</u>			
2537 Spar Caps (Longos)	20	-	
2531 Spar Tube No. 1, Incl Mandrel Prep	24	-	
2532 Spar Tube No. 2, Incl Mandrel Prep	24	-	
2533 Spar Tube No. 3, Incl Mandrel Prep	24	-	
2545 Outer Skin	8	-	
Subtotal	100	0	30
<u>Non-Cured Wet Layup Parts</u>			
2569 Inner Skin	16	-	
2538 Doubler Assy (Skin)	8	-	
2539 Inboard Doubler (Cap)	8	-	
2575 Inboard Doubler Filler	6	-	
Subtotal	38	0	10

TABLE 15. CMRB FABRICATION MAN-HOURS (CONT)

	Composites Laboratory	Other Fabrication	Manufacturing Engineering Planning Material Control
Blade Mold Co-Cure			
Prepare Mold and Assemble all Necessary Premade and Wet Parts, Cure Blade	80	-	
Trim Cured Blade (Remove Spar Tube, Mandrels, etc.)	22	-	
Machine Root End Bushings	1	22	
Send out to X-ray	1	-	-
Subtotal	104	22	30
Parts Premade and Bonded to Blade in Trim and Finish			
2511 Inboard Closure	30	-	
2576 Outboard Closure	20	-	
2517 Bracket Assembly	16	-	
Anodize	-	2	
2561 Tab Hinges	10	-	
Anodize	-	2	
2533, 2554 Backing Strips, Etch and Prime	1	4	
2515 Bolts, Passivate	1	2	
Subtotal	78	10	20
Final Blade Assembly			
Bond on Outboard Closure	32	-	
Bond Lightning Screen to Outboard Closure	12	-	
Prepare and Bond on Outboard Closure Cap	6	-	
Bond De-icer Blanket	34	-	
Bond Metal Tab Hinges	30	-	
Bond on Capping to Trailing Edge	10	-	
Bond on Backing Strips	20	-	
Bond on Inboard Closure	20	-	
Repair Surface Defects	30	-	
Bond on Erosion Strip	16	-	
Electrical Hook-up of De-icer Blanket	1	8	
Painting (Primer and Topcoat)	1	10	
Balance Completed Blade and Weigh	-	4	
Box and Ship	4	-	
Subtotal	216	22	60
TOTAL	778	84	220
Add 20 percent of shop labor for Quality Control	172		
TOTAL MAN-HOURS	1,254		

TABLE 16. EXPENDABLE MATERIALS
1981 DOLLARS

Material	Unit Price	Quantity	Cost
Peel Ply (Airtech)	$ 3.65/yd	1 yd	$ 3.65
Peel Ply (Tool Tech)	7.64/yd	1 yd	7.64
Tedlar Film (1 mil)	9.50/lb	1.72 lb	16.34
Primer P-5-2 (Thixon)	25.00/gal.	1 qt	6.25
Nylon Tube (4.75 in Dia)	13.25/lb	2.4 lb	31.80
Polyethylene Film	1.22/lb	100 yd (1.91 lb)	2.84
Paint - Acrylic	28.00/gal.	1 gal.	28.00
Primer	28.00/gal.	2 qt	14.00
Trichlorothane	9.50/gal.	2 qt	4.75
Isopropyl Alcohol	28.75/cwt	2 gal.	1.04
Methylethylkeytone	28.75/cwt	2 gal.	1.04
PVA Release Film	5.50/gal.	1 gal.	5.50
Ram 225 Mold Release	12.50/3 lb	1 lb	4.16
Wax	7.00/3 lb	1 lb	2.33
Teflon Pins	10.00/ft	1 ft	10.00
Selant Tape	25.00/cs	1 cs	25.00
Double Back Tape	25.00/cs	1/2 cs	12.50
Miscellaneous	-	-	25.00
		TOTAL	$201.54

TABLE 17. ENGINEERING COMPONENTS 1981 DOLLARS

Material	Unit Price	Qty Reqd (Per Blade)	Cost (Per Blade)
E-Glass Fabric (120)	$ 1.35/yd	4 yd	$ 5.40
E-Glass Fabric (1581)	1.66/yd	1.27 yd	2.10
Graphite Fabric (ES 1252A)	51.24/yd	35 yd	1,793.40
Kevlar 49 Roving	9.00/lb	61.96 lb	557.64
Apco Resin 2434	10.80/gal. (9.3#)	89.6 lb	104.00
Apco Hardener 2180	21.60/gal. (8.8#)	0.08 lb	2.00
Apco Hardener 2340	26.80/gal. (9.2#)	5.51 lb	18.00
Apco Hardener 2347	17.61/gal. (8.5#)	4.91 lb	9.00
Hysol EA 934 Adhesive	20.60/kit (4#)	4 lb	20.60
BF Goodrich Adhesive	7.00/kit	1 kit	7.00
Thermoform Adhesive	21.87/roll	2 rolls	43.74
FM 123 Film Adhesive	1.37/sq ft	2 ft	2.74
Milled Fiber E-Glass	0.72/lb	2.4 lb	1.73
Micro Balloons (FT102)	10.40/lb	2.3 lb	23.92
USC Urethane Foam	150.00/kit (50 lb/kit)	1.7 lb	5.10
MS200995C20 (Gauges and Wire)		A/R	600.00
Honeycomb HRH10-3/16 -2.0 and 3.0			300.00
Kevlar Fabric	7.57/yd	12 yd	90.85
Graphite Roving T300 (6000 Fil)	26.00/lb	3 lb	78.00
Film Adhesive 9628	1.29/sq ft	28 sq ft	36.12
	TOTAL		$3,705.68

TABLE 18. PURCHASED PARTS
1981 DOLLARS

Material	Unit Price	Quantity	Cost
7-311412514-3, -5, -7 Weights	$ 16.14/set	1	$ 16.14
7-311412514 Weight Adj	22.55	1	22.55
7-311412515-3 Bolt Adj	17.00	1	17.00
7-311412515-5 Bolt Adj	17.00	1	17.00
7-311412516 Erosion Strip	90.00	1	90.00
7-311412519 Bushing	75.58	4	302.32
7-311412547 Lightning Screen	4.71/sq ft	29	136.59
7-311412553 Backing Strip	24.73	2	49.46
7-311412517 Bracket	100.00	1	100.00
M83723-83R814N Receptacle	19.10	1	19.10
M83723-15A18A Backshell	15.80	1	15.80
7-311412512 Door, Fwd	25.00	1	25.00
7-311412512-3 Door, Aft	25.00	1	25.00
7-311412561 Tab Hinge	25.00	10	25.00
316RES Wire Rod	6.90	53	365.70
7-311412546 De-icer Blanket	923.00	1	923.00
7-311412554 Backing Strip	150.00	1	150.00
7-311412548 Fwd Tip Weight	350.00	1	357.50
7-311412549 Aft Tip Weight	630.00	1	239.17
7-311412550 Wt LE Tip	275.00	1	275.00
		TOTAL	$3,171.33

TABLE 19. LOW COST HARDWARE
1981 DOLLARS

Material	Unit Price	Quantity	Cost
AN960C616 Washer	$1.00 (Approx)	2	$ 2.00
NAS560HK3-1 Screw	1.00 (Approx)	8	8.00
AN960C10L Washer	1.00 (Approx)	5	5.00
HS4899-18M098 Cover	1.00 (Approx)	1	1.00
MS21042-3 Nut	1.00 (Approx)	3	3.00
MS21043-04 Nut	1.00 (Approx)	4	4.00
MS21044-N6 Nut	1.00 (Approx)	2	2.00
MS51957-15 Screw	1.00 (Approx)	4	4.00
MS9549-04 Washer	1.00 (Approx)	4	4.00
NAS1303-21 Bolt	1.00 (Approx)	3	3.00
NAS21042-5 Nut	1.00 (Approx)	2	2.00
NAS62050-52 Bolt	1.00 (Approx)	2	2.00
HS4249L1032 Insert	1.00 (Approx)	2	2.00
HS4249L10327-7 Spacer	1.00 (Approx)	2	2.00
AN970-5 Washer	1.00 (Approx)	4	4.00
HS4800-216 Splice	1.00 (Approx)	1	1.00
NAS603-6 Screw	1.00 (Approx)	2	2.00
		TOTAL	$49.00

Direct Material Cost = $7,128.00

Burdened Material Cost = $9,376.00

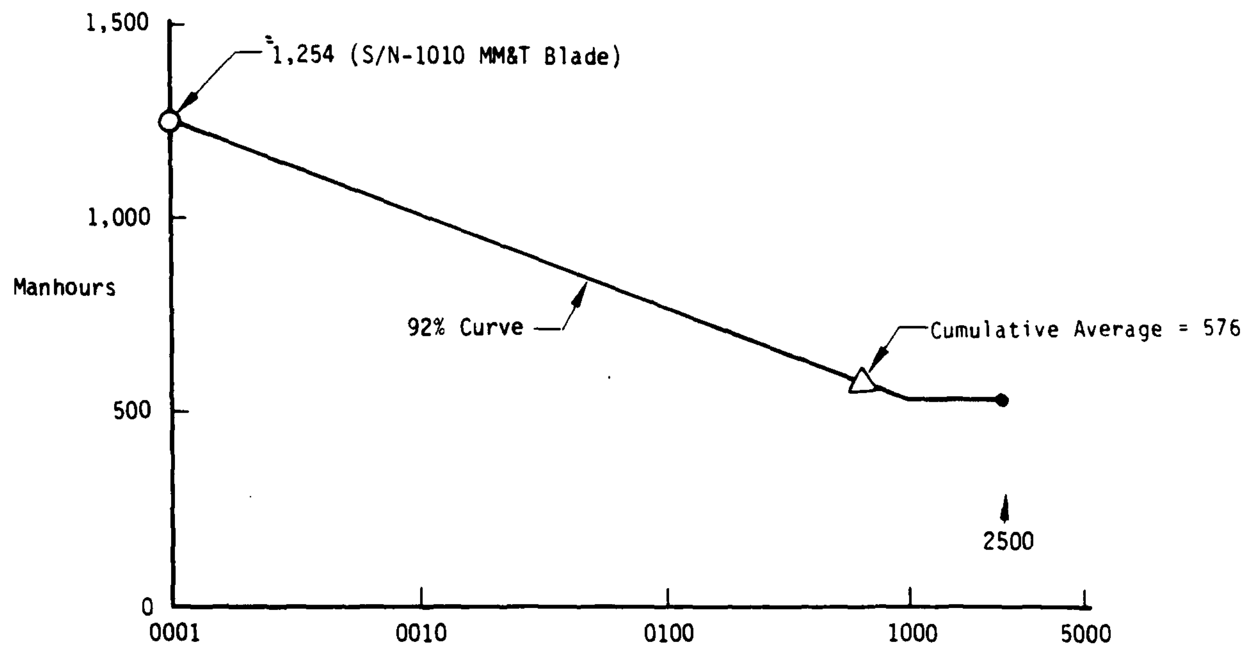


Figure 65. Man-hours for CMRB production.

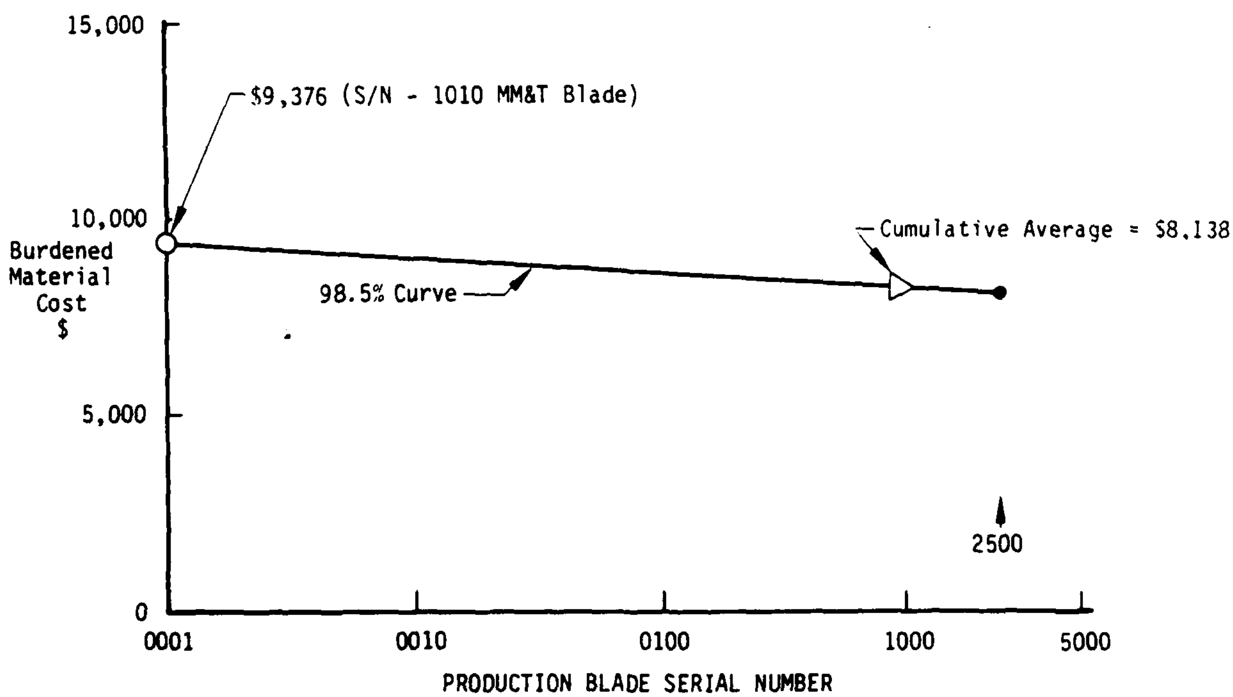


Figure 66. Burdened material cost for CMRB production.

PROCESS SPECIFICATION

This is the process specification to be used to fabricate the CMRB. The text paragraphing generally conforms to the form prescribed by Appendix XIV, Process Specification, MIL-STD-490. Upon approval as a process specification, this section is amenable to complete formatting in accordance with MIL-STD-490.

This process specification presented here is based largely on the production development work done by HH on the MTS Blade Program (Contract DAAJ02-74-C-0055).

1. SCOPE

1.1 This process bulletin establishes the materials and processes required to fabricate the Model 77 composite main rotor blade (CMRB) PN 7-311412500. It is currently in preliminary form and will be finalized before production begins.

2. APPLICABLE DOCUMENTS

2.1 Government documents. The following documents, of the issue in effect on date of the initiation for bids or request for proposal, form a part of this specification to the extent specified herein. In case of conflict between these documents and this specification, the requirements of this specification shall prevail.

SPECIFICATIONS

Federal

QQ-W-423	Wire, Steel, Corrosion Resisting
RR-W-360	Wire Fabric, Industrial
TT-I-735	Isopropyl Alcohol
TT-M-261	Methyl Ethyl Ketone, Technical
MMM-A-132	Adhesive, Heat Resistant, Airframe Structural, Metal to Metal

Military

MIL-C-9084	Cloth, Glass, Finished, for Resin Laminates
MIL-T-21014	Tungsten Base, High Density Metal (Sintered or Hot Pressed)
MIL-A-21180	Aluminum Alloy Casting, High Strength
MIL-S-22473	Sealing, Locking and Retaining Compounds, Single-Component
MIL-R-60346	Roving, Glass, Fibrous (for Filament Winding Applications)

2.1.1 Copies of specifications, standards, drawings, and publications required by vendors in connection with specified procurement functions should be obtained from the procuring activity or as directed by the contracting officer.

2.2 Non-Government documents. The following documents, of the latest issue in effect, form a part of this specification to the extent specified herein. In case of conflict between these documents and this specification, the requirements of this specification shall prevail.

SPECIFICATIONS

Hughes Helicopters, Inc.

EPB 4-230	Finish Specification for Model 77, Advanced Attack Helicopter
EPB 16-139	Procedure for Bonding of Polyurethane Erosion Strips to Composite M/R Blade (AAH)
EPB 30-164	Balancing Procedure for Model 77, M/R Blades PN 7-311412500
HMS 16-1068	Adhesive, Epoxy, Paste Type
HMS 16-1069	Adhesive, Metal-to-Metal Bonding, High Peel Strength, Rapid Curing
HMS 16-1111	Film Adhesive, Metal-to-Metal Bonding, High Structural Strength, Moisture Resistant
HMS 16-1114	Nylon Fiber Reinforced Honeycomb (Nomex)
HMS 16-1115	Resins, Epoxy, Filament Winding, for Structural Applications
HMS 16-1147	Adhesive, Epoxy, Two-Component
HMS 16-1163	Graphite Reinforcement, Yarn and Fabric

HMS 16-1164	High Strength Organic Fiber (Kevlar) Reinforcements, Yarn and Fiber
HMS 16-1171	Adhesive for Polyurethane Bonding
HMS 17-1172	Polyurethane, Rain Erosion Resistant Elastomer
HMS 17-1175	Polyurethane Foam, Self-Skinning, Self-Extinguishing, Closed Cell, Rigid
HP 1-17	Heat Treatment of 17-4PH and 15-5PH Precipitation Hardenable Corosion Resistant Steels
HP 4-35	Anodic Treatment of Aluminum Alloys for Metal-to-Metal Bonding
HP 5-10	Environmental Sealing
HP 6-3	Torquing of Aircraft Bolts, Screws, and Nuts
HP 6-5	Magnetic Particle Inspection
HP 8-5	Identification of Detail Parts and Assemblies
HP 9-20	Etching and Priming of Tungsten Alloys for Adhesive Bonding
HP 9-26	Etch and Prime of Austenitic Corrosion-Resistant Steel for Adhesive Bonding
HP 10-7	Shelf Life
HP 15-42	Fabrication of Reinforced Plastics
HP 15-45	Application of Liquid Locking Compound for Sealing and Retaining Metal Fasteners, Bearings, and Bushings
HP 15-67	Fabrication of Composite Parts by Filament Winding Method
HP 16-21	Structural Metal-to-Metal Bonding

HP 16-25	Bonding of Metallic and Nonmetallic Materials
HP 16-30	Bonding, High Structural Strength Metallic, Nonmetallic, and Honeycomb

2.2.1 Unless otherwise specified by the contracting officer, Hughes Helicopters, Inc. (HHI) documents should be obtained from the HHI Materials, Processes and Standards Department. Other industry documents should be obtained from the originating activities. Technical society and association documents are generally available from libraries, and are also distributed to technical groups and using Federal agencies.

3. REQUIREMENTS

3.1 Equipment tooling. The special equipment tooling needed to fabricate the CMRB shall include the following items, listed by HHI part number, and shall also include any and all special equipment needed to meet the requirements of this specification, including all tests and inspections listed in Section 4.

7-311412600	Billet mold aluminum
7-311412602	Airfoil templates
7-311412603	Mold die — blade
7-311412604	Mandrel for spar tube 1
7-311412605	Mandrel for spar tube 2
7-311412606	Mandrel for spar tube 3
7-311412610	Skin mandrel
7-311412611	Root end closure mold
7-311412612	Leading edge weight mold
7-311412613	Tip closure mold
7-311412614	Tip core mold

7-311412615	Forward channel mold
7-311412616	Aft channel mold
7-311412617	Trailing edge longo mold
7-311412618	Root end wedge mold
7-311412619	Form block
7-311412620	Root end dam mold
7-311412625	Template (erosion strip buildup)
7-311412629	Index plate, end plate
7-311412630	Tool assembly layout
7-311412632	Template guide setup
7-311412633	End dome detail winding mandrel
7-311412636	Spar broom winding fixture
7-311412638	Spacer — tip core and mold
7-311412639	Skin layup layout
7-311412640	Bushing location fixture
7-311412641	Blade cooling fixture
7-311412642	Root end dam locator
7-311412643	Filler — dummy tube and trailing edge longo
7-311412644	Tip weight locator
7-311412645	Spar wedge template
7-311412646	Template spar cap tip
7-311412647	Staging table

7-311412648	Strip — skin trailing edge skin doubler
7-311412649	Template (shop aid)
7-311412650	Mounting angle — tip core locator assembly
7-311412651	Template inner skin
7-311412652	Mold root end filler
7-311412653	Tip closure bonding fixture
7-311412655	Drill jig — root end

3.2 Materials. The materials used in fabricating the CMRB shall consist of the engineering materials and shop aids listed in 3.2.1 and 3.2.2, and shall be handled as described in 3.2.3 and 3.2.4.

3.2.1 Engineering materials.

Aluminum castings (MIL-A-21180)

Clear paste adhesive (HMS 16-1068, Class 3)

E-glass fiber, Style 1581 (MIL-C-9084, Type VIIIA, Class 2)

E-glass milled fiber, 1/32-inch (0.794 mm)

Film adhesive (HMS 16-1069)

Film adhesive (HMS 16-1111)

Foaming Adhesive (HMS 16-1111)

Graphite fabric, 8 harness satin weave (HMS 16-1163, Type II, Class I, Grade A)

Graphite roving, 6000 filament (HMS 16-1163, Type I, Class 2)

Kevlar 49 fabric, Style 281 (HMS 16-1164, Type II, Class 2)

Kevlar 49 roving, 1420 denier (HMS 16-1164, Type I, Class 3)

Lightning screen (5056 aluminum, twill mesh, RR-W-360, Type I, Class 2)

Microballoons

Polyurethane erosion strip bonding adhesive and primer (HMS 16-1171)

Polyurethane erosion strip banding adhesive and primer (HMS 17-1172)

Resin and hardeners (HMS 16-1115)

S-glass roving (MIL-R-60346, Type IV, Class 1)

Tungsten (MIL-T-21014)

Urethane foam (HMS 17-1175)

Wire rods, 316 CRES (QQ-W-423)

3.2.2 Shop aids.

Double-back tape

Isopropyl alcohol (TT-I-735)

Metal spacer

Methyl ethyl ketone (MEK) (TT-M-261)

Mold release (Ram 225, or equivalent)

Peel ply (Air Tech, Tool Tech, or equivalent)

Polyethylene, film, 2-mil, embossed

Polyvinyl alcohol

Scrim cloth

Sealant tape

Styrofoam, sheet, 1/2-inch (12.7 mm)

Tedlar film, 1-mil

Teflon plugs

Wax (Trewax, or equivalent)

Wrightlon tube (Vac Pac, 3-mil) (7400 LF, 0.003)

3.2.3 Materials handling. Adhesives, resins, and rovings require special handling and shall be stored and handled in accordance with their governing material specifications and HP 15-67 prior to use.

3.2.4 Shelf life. The shelf life of the HMS 16-1068 and HMS 16-1147 adhesives is 1 year, and that of the HMS 16-1069 and HMS 16-1111 film adhesives is 6 months when stored as required by the applicable material specifications.

NOTE

> The shelf life may be extended by retest for periods not to exceed the requirements of HP 10-7.

3.3 Procedures.

3.3.1 Preproduction facility control.

3.3.1.1 Temperature and relative humidity. The temperature and relative humidity shall be maintained in accordance with the controlling process specifications of HP 15-67.

3.3.1.2 Cleaning. Work surface, bench tops, and other assembly areas shall be maintained in a clean manner consistent with their intended use by the following methods: water mopping with wet or dampened mops; vacuuming; chemical mopping using commercially treated tacky mops. Cleaning is required on a regular schedule and also whenever visual inspection shows any accumulated dust, dirt, or other contamination.

3.3.1.3 Separations. Compounds containing uncured silicones, waxes or any material detrimental to adhesion shall be kept segregated from bond assembly, resin, adhesive, and primer storage areas.

3.3.1.4 Filters for contamination control. Filters for airborne dust, traps for moisture and oil, and vacuum pump outlets for press curing of adhesives shall be installed to avoid substances detrimental to adhesion.

3.3.1.5 Calibration and certification of temperature and pressure instrumentation. Calibration charts and certification records shall be maintained on file for a minimum of 3 years and shall be made available for inspection upon request by Hughes Helicopters, Inc.

3.3.2 Fabrication of reinforced plastic subassemblies. Reinforced plastic subassemblies shall be fabricated in accordance with HP 15-42 and HP 15-67. Colored cotton thread may be used within the fiberglass laminates to indicate the fiber orientation.

3.3.2.1 Fiberglass subassemblies shall be fabricated with a nylon peel ply which shall be removed just prior to the bonding operation. All peel plies shall be marked "Remove Peel Ply" with letters no smaller than 1/4 inch (6.35 mm) in accordance with HP 8-5.

3.3.2.2 Fiberglass may be spliced in the filler area and 60-degree wraps of spar tubes only. Splices shall be overlapped at least 1 inch (25.4 mm).

3.3.2.3 Fiber volume requirements and dry:wet fiber weight ratios are specified below.

3.3.2.3.1 A 50-percent fiber volume and a 0.56 ±0.03 dry:wet fiber weight ratio are required for Kevlar 49 fabric and rovings.

3.3.2.3.2 A 55-percent fiber volume and a 0.60 ±0.03 dry:wet fiber weight ratio are required for graphite fabric and rovings.

3.3.2.3.3 Fiber volume and dry:wet fiber weight ratios shall be performed as required by this EPB in accordance with the techniques specified in HP 15-67.

3.3.2.4 Storage of any filament wound or other uncured component awaiting incorporation into a blade shall be done at low temperatures, in accordance with the guidelines set forth in HP 15-67.

3.3.2.5 HMS 16-1164 (Kevlar) yarns and fabrics shall be dried out prior to impregnation in accordance with HP 15-67.

3.3.3 Fabrication records. The following information is required to be recorded in the individual planning for each blade fabricated (including individual components).

3.3.3.1 Fabrication, start and completion time.

3.3.3.2 Lot, batch, or any other applicable identification numbers for all materials used.

3.3.3.3 Resin mixing, dates and times.

3.3.3.4 Relative humidity at the time of impregnation of any fabric or yarn.

3.3.4 Metal components. The various metal components requiring chemical processing or any other preliminary operation shall be processed as follows.

3.3.4.1 Weight retention fitting aft (7-311412549). The aluminum casting weight retention fitting shall be processed as follows.

3.3.4.1.1 Anodize and prime in accordance with HP 4-35.

3.3.4.1.2 Apply one layer of adhesive to all exterior surfaces, using HMS 16-1069, Class 2 or Class 3, in accordance with HP 16-21. Exterior shall have one layer of peel ply for future applications.

3.3.4.1.3 Identify in accordance with HP 8-5. Do not remove peel ply, and seal in polyethylene bag until ready for further use.

3.3.4.2 Weight retention fitting, forward (7-311412548). The 17-4PH steel weight retention fitting shall be processed as follows.

3.3.4.2.1 Heat treat to condition H 1000 in accordance with HP 1-17.

3.3.4.2.2 Etch and prime in accordance with HP 9-26.

3.3.4.2.3 Apply adhesive as in 3.3.4.1.2 and identify and store as in 3.3.4.1.3.

3.3.4.3 Bushings, attach (7-311412568). The 17-4PH bushings shall be processed as follows.

3.3.4.3.1 Magnetic particle inspect in accordance with HP 6-5.

3.3.4.3.2 Heat treat to condition H 1025 in accordance with HP 1-17.

3.3.4.3.3 Etch and prime in accordance with HP 9-26.

3.3.4.3.4 Apply adhesive to the tubular portions as in 3.3.4.1.2.

3.3.4.4 Leading edge balance weight rods. The 316 CRES stainless steel balance rods shall be processed as follows.

3.3.4.4.1 The required number and lengths are as specified in 3.3.6.1.1.

3.3.4.4.2 Etch and prime the cut rods in accordance with HP 9-26.

3.3.4.4.3 Identify in accordance with HP 8-5 and seal in a polyethylene bag until ready for use.

3.3.4.5 Tungsten leading edge balance weight. The tungsten balance weight shall be prepared as follows.

3.3.4.5.1 Etch and prime in accordance with HP 9-20.

3.3.4.5.2 Identify in accordance with HP 8-5 and seal in a polyethylene bag until ready for use.

3.3.4.6 Backing strips. The 301 CRES stainless steel backing strips shall be processed as follows.

3.3.4.6.1 Etch and prime in accordance with HP 9-26.

3.3.4.6.2 Identify in accordance with HP 8-5 and seal in a polyethylene bag until ready for further use.

3.3.4.7 Aluminum wire mesh (7-311412547). The 5056 aluminum lightning screen (RR-W-360, Type I, Class 2) shall be processed as follows.

3.3.4.7.1 Clean using MEK (TT-M-261) spray, repeated as required to remove any visible contamination.

3.3.4.7.2 Identify in accordance with HP 8-5 and seal in a polyethylene bag until ready for further use.

3.3.5 Curing. The minimal acceptable cure cycle is dependent on the adhesive and resin system used. The most frequently used acceptable cure cycles are as follows. When any deviation from these is used it must be with the consent of the HHI Materials Processes and Standards Department, as indicated by the signature of the cognizant MP&S engineer on the applicable shop planning.

3.3.5.1 Subassemblies fabricated using HMS 16-1115 Type II resin and hardener shall be allowed to cure a minimum of 12 hours at room temperature (75°F (24°C) minimum) prior to the removal of any pressure restraining devices.

3.3.5.2 Subassemblies fabricated using HMS 16-1115 Type I, Class 3 resin and hardener shall be allowed to cure a minimum of 12 hours at room temperature with the same restrictions as in 3.3.5.1, or a heat cure of 3 hours ±20 minutes at 140° ±10°F (60° ±5.5°C).

3.3.5.3 Subassemblies fabricated using HMS 16-1115, Type I, Class I resin and hardener shall be allowed to cure a minimum of 72 hours at room temperature with the same restrictions as in 3.3.5.1, or a heat cure of 3 hours minimum at 170° ±10°F (77° ±5.5°C).

NOTE

> Paragraph 3.3.5.3 refers only to subassembly parts which will see the final co-cure process as parts of the main blade assembly, as in 3.3.5.4. (All other subassembly parts must be subjected to cure cycle before assembly.)

3.3.5.4 Final mold co-cure cycle.

3.3.5.4.1 Raise the heat of the part to 150° ±10°F (66.6° ±5.5°C) at a rate of approximately 1°F (0.6°C) per minute. Hold at 150° ±10°F (66.6° ±5.5°C) for 3 hours ±15 minutes. Raise the heat of the part to 300° ±10°F (148.9° ±5.5°C) over a 3.5-hour ±15-minute period.

NOTE

> Several intermediate steps, not to exceed increments of 20°F (11°C) may be used to facilitate tooling capabilities, provided the 5-hour minimum, ultimate heat ramp is achieved.

3.3.5.4.2 Hold at 300° ±10°F (148.9° ±5.5°C) for 60 -0, +30 minutes.

3.3.5.4.3 Cool the entire part below 150°F (66°C) before removing from the mold.

3.3.6. Surface defects. Surface defects shall be treated as follows.

3.3.6.1 Voids less than 0.125 inch (3.175 mm) in depth are acceptable.

3.3.6.2 Voids greater than 0.125 inch (3.175 mm) in depth shall be repaired as follows:

WARNING

Fire hazard; solvent is dangerous when exposed to heat or flame; use only with plenty of ventilation away from smoke and flames. Flashpoint 22°F (-5.5°C).

3.3.6.2.1 Solvent wipe area with TT-M-261 MEK.

3.3.6.2.2 Scuff sand the area with 180 - 320 grit paper to remove any gloss from the resin surface. Solvent clean as in 3.6.3.2.1.

3.3.6.2.3 Mix and apply HMS 16-1068, Class 3 adhesive in accordance with HP 16-25, filling voids flush with the surrounding surfaces.

3.3.7 Secondary bonding operations.

3.3.7.1 Film adhesive bonding operations shall use HMS 16-1111, Class 3 adhesive in accordance with HP 16-30.

3.3.7.2 Paste adhesive bonding operation shall use HMS 16-1068, Class 3, adhesive in accordance with HP 16-25.

3.3.7.3 Electrical connections shall be sealed using HMS 16-1147, Class 2 adhesive in accordance with HP 5-10.

3.3.7.4 The 7-3114152516-11 erosion strip shall be bonded in accordance with EPB 16-139.

3.3.8 Finish (paint). Finish in accordance with EPB 4-230.

3.3.9 Weight and balance. Weight and balance procedures shall be in accordance with EPB 30-164. Install weight retention fitting doors and secure fasteners using MIL-S-22473, Grade C in accordance with HP 15-45. Torque fasteners to 25–35 inch-pounds (2.8–4.0 N·m) in accordance with HP 6-3.

4. QUALITY ASSURANCE

4.1 Provisions of the NDE plan apply.

4.2 Test methods. Tests and inspections shall be performed to assure conformance to the requirements of Section 3.

4.2.1 Film adhesive bonded assemblies shall be verified by the use of lap shear tensile specimens, prepared in accordance with MMM-A-132, processed with each bonding cure cycle. The substrates shall be aluminum, anodized and primed in accordance with HP 4-35. The processing operations shall be representative of those of the actual blade. The minimal acceptable value for HMS 16-1111 Class 3 adhesive is 4 ksi (20.7 MPa) and for Class 6 is 5 ksi (34.5 MPa).

4.2.2 Paste adhesive bonded assemblies shall be verified by the use of potted samples to be checked for hardness to verify mix and curing only. The minimum shore D value for HMS 16-1068, Class 3 adhesive is 60. The minimum shore D value for HMS 16-1147, Class 2 adhesive/sealant is 50.

4.2.3 Identification of the test specimens shall be such that they will be readily traceable to the curing lot and to the bonding assemblies or laminates in that lot.

4.2.4 No test specimens shall be required of the bonding cure cycle of the lower skin and core assembly. Visual examination shall be sufficient to determine acceptable bonding.

4.3 Test blades. Requirements for periodic destructive testing of blades have yet to be determined. A blade will be selected at random to be evaluated for root and tip end ultimate and various other destructive test methods to verify consistency within the manufacturing process.

4.4 Remainder of the main rotor blade.

4.4.1 The contour and twist shall be checked using Sta 216 (75 percent radius) as a reference.

4.4.2 All other Quality Acceptance criteria shall be in accordance with HHI 79-213 (NDI Test Plan) and HHI 79-216 (QA Acceptance Criteria Plan) until such time as these can be incorporated into this EPB.

5. PREPARATION FOR DELIVERY

Not applicable.

6. NOTES

6.1 Intended use. This process is intended for use in the fabrication of the composite main rotor blades for the Model 77 helicopter.

7. APPROVED VENDORS

Not applicable

PROCESS SPECIFICATION

COMPOSITE MAIN ROTOR BLADE FOR YAH-64 HELICOPTER

1. SCOPE

The specification defines the materials and processes required for fabricating the composite main rotor blade (CMRB) for the YAH-64 helicopter.

2. APPLICABLE DOCUMENTS

2.1 Drawing No. 6-311412500 (Figure A-1 Appendix C).

2.2 Process Specification, HP 9-26D: Etch and Priming of Austenitic Corrosion-Resistant Steel for Adhesive Bonding.

2.3 Process Specification, HP 4-35F: Anodic Treatment of Aluminum Alloys for Metal-to-Metal Bonding.

2.4 Process Specification, HP 4-7A, Parco Lubrite, Phosphate Coating of Steel.

2.5 Process Specification, HP 15-38C: Installation of Bearings/Bushings.

2.6 Process Specification, HP 9-1-J: Abrasive Cleaning Methods for Metallic and Nonmetallic Parts.

3. REQUIREMENTS

The CMRB is designed to be a direct replacement (in four-blade sets) for the metal blade currently installed on YAH-64 helicopters. Its planform, twist, and airfoil section (outboard of Blade Station (BS) 83) are the same as the metal blade. Its weight distribution and dynamic properties are equivalent. The blade is made by the wet filament winding (WFW), cocure process and is made entirely of composite materials with the exception that retention bolt bushings at the root end, the tip weights and leading edge weights are metal, the de-icer has metallic heating elements, and the erosion strip is polyurethane.

3.1 Equipment. The special equipment needed to fabricate the CMRB shall consist of:

3.1.1 Heat press

3.1.2 Steam generator

3.1.3 Aluminum main mold — 2 halves

3.1.4 Winding mandrel — outer skin

3.1.5 Winding mandrel — spar tubes

3.1.6 Winding mandrel — doublers

3.1.7 Winding fixture — longos

3.1.8 Filament winding machine

3.1.9 Longo hardback

3.1.10 Root end filler mold — 2 required

3.1.11 Tip end filler mold — 4 required

3.1.12 Root end longo tray

3.1.13 Leading edge weight mold

3.1.14 Tip area tab mold

3.1.15 Inboard closure rib mold

3.1.16 Outboard closure rib mold

3.1.17 Root end machining fixture

3.1.18 Static balance machine

3.2 Materials. The materials required to fabricate the CMRB blade shall be as listed below:

3.2.1 Kevlar-49, 1420 denier roving*

3.2.2 Style 181 kevlar fabric

3.2.3 Style 1581 E — glass fabric

3.2.4 Milled E-glass fibers mixed with paragraph 3.2.8 epoxy resin system. Fiber ratio = 0.50 by weight.

3.2.5 Milled E-glass fibers mixed with paragraph 3.2.9 epoxy resin system. Fiber ratio = 0.20 by weight.

3.2.6 Syntactic Foam — Emerson and Cumings FT-102 glass microballoons mixed with paragraph 3.2.8 epoxy resin system. Mixing ratio 20 percent by weight (20 parts microballoons, 80 parts resin).

3.2.7 Syntactic Foam — Emerson and Cumings FT-102 glass microballoons mixed with paragraph 3.2.9 epoxy resin system. Mising ratio 20 percent by weight (20 parts microballoons, 80 parts resin).

3.2.8 APCO 2434/2347 epoxy resin system, 7.5 ±0.5 parts per hundred resin by weight (phr).

3.2.9 APCO 2434/2340 epoxy resin system, 27 ±1.0 phr.

3.2.10 Mold release: "Part-All No. 10," Rexco.

3.2.11 Mold wax: "Mirror Glaze" or equivalent.

3.2.12 Mold release: "Ram 225," Ram Chemical Co.

3.2.13 Polyvinyl alcohol (PVA) emulsion or equivalent.

3.2.14 Film adhesive FR-7035 (nylon matte carrier) 0.03 pound per square foot, Fiber Resin Corporation.

3.2.15 5056 Aluminum screen, 200 x 200 mesh, 2-mil wire diameter.

*See Table 20 for filament density characteristics.

TABLE 20. COMPOSITE MATERIAL DENSITY

	Fiber		Resin	Composite	
Type of Fiber	Density lb/in^3	Area $in.^2 \times 10^{-6}$	Density $lb/in.^3$	Fiber/Resin Volume Percent	Density $lb/in.^3$
Kevlar 49	0.0524	168.66	0.0412	50	0.0468
E-Glass	0.0920	83.35	0.0412	50	0.0666

The number of rovings and bands specified for WFW operations in paragraph 3.3 are based upon the fiber density values shown above. Spools of filaments used to form the roving bands shall be individually selected to achieve an overall accuracy of density to within ±5 percent.

3.2.16 Peel ply nylon cloth, Miltex 3921 or equivalent (Shop Aid).

3.2.17 SP110 cleaner, J.S. Switzer Associates.

3.2.18 Polyethelyne film, 2-mil thick with texturized surface.

3.2.19 Tedlar film, bondable both sides, 4 mil, clear, Dupont.

3.2.20 3/32 inch diameter 4130, 125,000 psi heat treat steel rod.

3.2.21 10C-2 filler, Advanced Coatings and Chemical Co.

3.2.22 28W-1 surfacer, Advanced Coatings and Chemical Co.

3.2.23 37038 black HMS15-1083 lacquer, FED-STD-595.

3.2.24 HMS 15-1100, Type I primer, FED-STD-595.

3.2.25 Capon 80, Vacuum bag material.

3.3 <u>Required procedures and operations.</u>

3.3.1 <u>Main mold preparation (surface and flanges of mold)</u>.

3.3.1.1 Apply paragraph 3.2.11 mold wax and buff.

3.3.1.2 Apply paragraph 3.2.12 mold release very lightly (blend equal parts by weight).

3.3.1.3 Spray mold with paragraph 3.2.13 emulsion and cure at room temperature until tack free.

3.3.2 Tray fabrication.

3.3.2.1 Laminate one ply of paragraph 3.2.3 glass fabric on patterns with paragraph 3.2.9 resin system.

3.3.2.2 Apply paragraph 3.2.16 peel ply; then enclose in vacuum bag and rub out.

○ 3.3.2.3 Cure 8 to 10 hours at room temperature.

3.3.2.4 Trim to size.

○ 3.3.2.5 Inspect dimensionally.

3.3.2.6 Store in a plastic bag until needed.

3.3.2.7 See paragraph 3.3.13 for next process step.

3.3.3 Outer skin fabrication (one required).

3.3.3.1 Weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry-to-wet-filament weight ratio should be 0.56 ±0.03.

○ 3.3.3.2 Set up the outer skin winding mandrel in the winding machine. Wrap one ply of paragraph 3.2.18 polyethelyne film around entire mandrel and tape into position. Measure the mandrel tare weight before.

○ 3.3.3.3 Wind according to Table 21 with paragraph 3.2.1 Kevlar-49 and paragraph 3.2.8 resin.

TABLE 21. SKIN WINDING PROGRAM

No. Rovings	Winding Angle*	No. Circuits per pattern	No. Circuits per layer	No. Layers	No. Plies
16	±45°	4	72***	4	–

*Tolerance ±5°
**Tolerance ±0.05 inch
***For a length of 260 inches

○ Indicates points that must be signed off by Quality Control Inspector.

○ 3.3.3.4 The weight of the wound assembly must conform to the limits shown in weight record (Table 24).

3.3.3.5 This part may be stored up to 48 hours at room temperature.

3.3.3.6 See paragraph 3.3.13 for next process step.

3.3.4 <u>Spar longo fabrication (four required).</u>

3.3.4.1 Surface treat and prime bushing surface according to paragraph 2.2.

○ 3.3.4.2 Measure hardback tare weight and mount hardback, tray, and bushing on longo winding fixture. Apply one piece of paragraph 3.2.14 film adhesive between the flange of bushing and tray. Remove peel ply. Wet the upper and lower tray surfaces with paragraph 3.2.8 resin. Tape down leading edge of tray.

3.3.4.3 Weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry-to-wet-filament weight ratio must be 0.56 ±0.03.

3.3.4.4 Wind the spar longo from paragraph 3.2.1 Kevlar-49 and paragraph 3.2.8 resin.

○ 3.3.4.5 Using 15 rovings per band, wind wraps as follows:

a. Make seven wraps around end bushings.

b. Add two pins at each end of hardback, starting at the center.

c. Make seven wraps around end bushings, add four pins.

d. Repeat steps b and c five times for a total of seven circuits with seven wraps each.

○ 3.3.4.6 The weight of the wound assembly must conform to the limits shown in the weight record (Table 24).

○ 3.3.4.7 If the wet winding is not to be used within 24 hours after winding, seal in plastic bag and store at temperature of +40°F maximum for up to 72 hours. After 72 hours this winding must be used immediately!

○ **Indicates points that must be signed off by Quality Control Inspector.**

3.3.4.8 See paragraph 3.3.13 for next process step.

3.3.5 Spar broom fabrication (four required — wind two at same time).

3.3.5.1 Mount hardback and tray with peel ply removed on broom winding fixture. Coat the upper and lower surface of the tray with paragraph 3.2.8 resin.

○ 3.3.5.2 Measure hardback tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry-to-wet-filament weight ratio must be 0.56 ±0.03.

3.3.5.3 Wind the broom from paragraph 3.2.1 Kevlar-49 and paragraph 3.2.8 resin.

○ 3.3.5.4 Using 14 rovings per band, wind 120 wraps around each pin on fixture.

○ 3.3.5.5 The weight of the wound assembly must conform to the limits shown in the weight record (Table 24).

○ 3.3.5.6 Store in cold box according to paragraph 3.3.4.7.

3.3.5.7 See paragraph 3.3.13 for next process step.

3.3.6 Root end reinforcement laminate (two required).

3.3.6.1 Weigh 60-foot lengths of dry filament and wet filament. Dry-to-wet-filament weight ratio should be 0.56 ±0.03.

3.3.6.2 Wrap skin mandrel with release film (paragraph 3.2.18).

3.3.6.3 Wind using paragraph 3.2.1 Kevlar-49 and paragraph 3.2.8 resin according to Table 22.

○ **Indicates points that must be signed off by Quality Control Inspector.**

TABLE 22. REINFORCEMENT WINDING PROGRAM

No. of Rovings	Winding Angle*	No. Circuits per Pattern	No. Circuits per Layer	Bandwidths** (inches)	No. Layers
16	±45°	4	72***	0.69	4
*Tolerance ±5° **Tolerance ±0.05 inch ***For a length of 260 inches					

3.3.6.4 Cut winding longitudinally and lay out flat on work table.

○ 3.3.6.5 Trim according to template and stack layers according to patterns. Remove release film for each layer.

○ 3.3.6.6 Store in cold box according to paragraph 3.3.4.7.

3.3.6.7 See paragraph 3.3.13 for next process step.

3.3.7 <u>Trailing edge longo fabrication.</u>

○ 3.3.7.1 Measure hardback tare weight, and weight 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry-to-wet-filament weight ratio must be 0.56 ±0.03.

3.3.7.2 Wind 14 rovings per band for a total of 13-1/2 wraps.

○ 3.3.7.3 The weight of the wound assembly must conform to the limits shown in the weight record (Table 24).

3.3.7.4 Place wet trailing edge longo in trailing edge longo mold. Vacuum bag with paragraph 3.2.25 material at 24 to 26 inch hg, and cure to the B stage.

3.3.7.5 Remove from the mold and seal in a plastic bag until ready for final assembly.

○ 3.3.7.6 See paragraph 3.3.13 for next process step.

○ Indicates points that must be signed off by Quality Control Inspector.

3.3.8 Leading edge weight.

○ 3.3.8.1 Surface treat and prime surfaces of paragraph 3.2.2 leading edge balance weight rods (81 pieces) with paragraph 2.4.

3.3.8.2 Place one layer of paragraph 3.2.3 E-glass fabric in leading edge weight mold.

3.3.8.3 Coat leading edge balance spar rods with paragraph 3.2.8 resin.

○ 3.3.8.4 Assemble spar rods and paragraph 3.2.5 milled fiber epoxy in leading edge mold. Fold paragraph 3.2.3 E-glass fabric over assembly.

○ 3.3.8.5 Seal paragraph 3.2.25 vacuum bag material over mold, apply vacuum (24 to 26 in. Hg), and cure to the B stage.

○ 3.3.8.6 Remove from the mold and seal in a plastic bag until ready for final assembly.

3.3.8.7 See paragraph 3.3.13 for next process step.

3.3.9 Spar tube fabrication (five required).

○ 3.3.9.1 Surface treat and prime surface of leading edge tip weight for No. 1 spar tube according to paragraph 2.4 and trailing edge weight for No. 3 spar tube according to paragraph 2.3.

○ 3.3.9.2 Install tip weight on winding shaft for spar tubes No. 1 and 3. Wrap tip weights with paragraph 3.2.14 film adhesive. Punch holes in film adhesive to allow free air passage through 1/8-inch diameter hole. Identify the spar tube number on each winding shaft.

3.3.9.3 Install styrofoam mandrels on winding shafts.

3.3.9.4 Install inner polyethylene bag and paragraph 3.2.19 bladder on mandrels. Seal to end domes.

3.3.9.5 Install mandrel in winding machine.

○ 3.3.9.6 Check bladder for leak under initial winding pressure and seal leaks if any.

○ Indicates points that must be signed off by Quality Control Inspector.

3.3.9.7 Measure mandrel tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry-to-wet filament weight ratio must be 0.56 ±0.03.

3.3.9.8 Wind sequence No. 1 of Table 23 with dry roving.

3.3.9.9 Wind all five tubes with paragraph 3.2.1 Kevlar-49 and paragraph 3.2.8 resin.

3.3.9.10 Wind tubes per winding program in Table 23.

3.3.9.11 Check wound tubes for leaks at 35 psi. Make new tube if leak is found.

3.3.9.12 The weight of the wound assemblies must conform to the limits specified in the weight record (Table 24). Note: Use plastic film-covered aluminum angle to support the wet-wound tubes while handling.

3.3.9.13 Store in cold box according to paragraph 3.3.4.7. Caution: Support on plastic film-covered aluminum angle in cold box.

3.3.9.14 See paragraph 3.3.13 for next process step.

3.3.10 Filler longo fabrication (five required).

3.3.10.1 Weigh 60-foot length of dry filament and wet filament before beginning to wind part. Dry-to-wet-filament weight ratio must be 0.56 ±0.03.

3.3.10.2 Wind filler longos from paragraph 3.2.1 Kevlar-49 and paragraph 3.2.11 resin.

TABLE 23. MAIN SPAR TUBE WINDING PROGRAM

Sequence No.	No. Rovings	Winding Angle*	No. Circuits per Pattern	No. Circuits per Layer	Bandwidth** (in.)	No. Layers	No. Plies
1	16	±45°		***	0.69	2	–
2	16	±45°		***	0.69	1	–

*Tolerance ±5°
**Tolerance ±0.05 inch
***For a length of 260 inches

○ Indicates points that must be signed off by Quality Control Inspector.

3.3.10.3 Usirg 16 rovings per band, wind 3 wraps around two pins.

3.3.10.4 The weight of the wound assembly must conform to the limits shown in the weight record (Table 24).

3.3.10.5 Store in the cold box according to paragraph 3.3.4.7.

3.3.10.6 See paragraph 3.3.13 for next process step.

3.3.11 <u>Backing strip fabrication</u>

3.3.11.1 Laminate two plies of paragraph 3.2.3 glass fabric on patterns with paragraph 3.2.9 resin system.

3.3.11.2 Apply paragraph 3.2.16 peel ply, then enclose in vacuum bag and rub out. Draw vacuum (26 in Hg) and check for leaks.

○ 3.3.11.3 Cure 8 to 10 hours at room temperature.

3.3.11.4 Trim to size.

○ 3.3.11.5 Inspect dimensionally.

3.3.11.6 Store in a plastic bag until needed.

3.3.11.7 See paragraph 3.3.13 for next process step.

3.3.12 <u>Inboard and outboard closure rib fabrication.</u>

3.3.12.1 Laminate six plies of paragraph 3.2.2 kevlar fabric on mold with paragraph 3.2.9 resin system.

3.3.12.2 Apply paragraph 3.2.16 peel ply, then enclose in vacuum bag. Draw vacuum (26 in. Hg) and check for leaks.

○ 3.3.12.3 Cure 8 to 10 hours at room temperature.

3.3.12.4 Trim to size.

○ 3.3.12.5 Inspect dimensionally.

3.3.12.6 Store in a plastic bag until needed.

○ Indicates points that must be signed off by Quality Control Inspector.

3.3.12.7 See paragraph 3.3.13 for next process step.

3.3.13 Assembly sequence (applies to both the upper and lower half molds unless otherwise specified.

3.3.13.1 Place a single layer of paragraph 3.2.15 aluminum screen over the entire area of lower mold half.

○ 3.3.13.2 Install leading edge de-icer cap.

3.3.13.3 Cut the outer skin winding at trim lines.

○ 3.3.13.4 Align edge of skin to trailing edge of mold cavity and place skin on lower mold.

3.3.13.5 Rub out with paint roller. Caution: Roll in chordwise direction; do not disturb winding pattern. Note: Use paint roller to remove air bubbles; use grooved Teflon roller to remove wrinkles.

3.3.13.6 Remove plastic film. Caution: Do not disturb winding pattern.

3.3.13.7 Install root-end reinforcement laminate (paragraph 3.3.6) with the big side down, taper steps facing up. Note: Fill cavity around bushing with paragraph 3.2.4 milled fiber.

3.3.13.8 Rub out root-end reinforcement laminate with paint roller.

○ 3.3.13.9 Install aft longo location.

○ 3.3.13.10 While on hardback, rub out spar longos first with slotted Teflon roller then finish with Teflon paddle to attain uniform pattern. Longo width outboard of BS 82 is 9.20 inches.

○ 3.3.13.11 Install trailing edge longo locator.

○ 3.3.13.12 Paint the leading edge weight (paragraph 3.3.8) with paragraph 3.2.8 resin and place it on the lower half mold.

3.3.13.13 Remove spar broom (paragraph 3.3.5) from hardback, brush bushing surface with paragraph 3.2.9 resin and install over spar longo on flanged bushing. Fair step-tapered ends of broom longos with milled fiber. Caution: Do not allow milled fiber to lift tray. Use flange bushing holding tool to compress fiber.

○ Indicates points that must be signed off by Quality Control Inspector.

3.3.13.14 Remove spar longo assembly (paragraph 3.3.4) from hardbacks using carrying strips and install with flange bushings in mold recess and longo trays fitted to mold. Line up trailing edge of longo with locators. Fill tray cavity with paragraph 3.2.4 milled fiber. Caution: Do not allow milled fiber to lift tray. Note: Install clamp fixture to hold down bushings.

3.3.13.15 Rub out paragraph 3.3.5 spar brooms per paragraph 3.3.13.9 while cutting the layers to a taper per drawing. Remove separation strips.

3.3.13.16 Install thermocouples according to Figure 67.

3.3.13.17 Fill cavities in tray and fair in spaces around root end of spar longos with milled fiber according to paragraph 3.2.4.

3.3.13.18 Coat paragraph 3.3.7 trailing edge with paragraph 3.2.8 resin and place on lower half mold, using paragraph 3.3.13.10 locator for alignment.

3.3.13.19 Fill holes in all-metal bushings with PVC foam (shop aid).

3.3.13.20 Remove spar longo locators (paragraph 3.3.13.8) and trailing edge longo locator (paragraph 3.3.13.10).

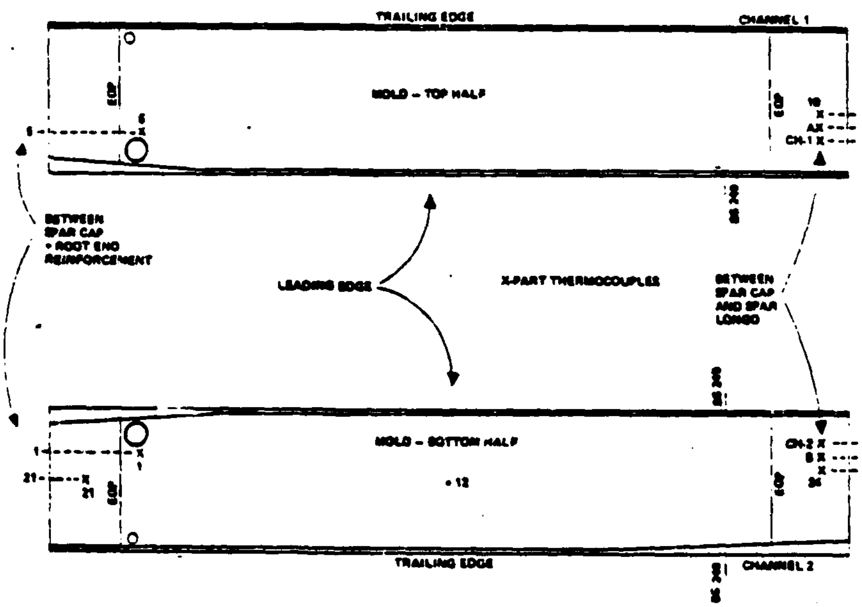


Figure 67. Thermocouple Location

○ Indicates points that must be signed off by Quality Control Inspector.

○ 3.3.13.21 Install five spar tubes and aft pressure bladder in lower mold placing five filler longos (paragraph 3.3.10) at lower intersections of spar tubes.

○ 3.3.13.22 Install five filler longos (paragraph 3.3.10) at top intersections of spar tubes.

○ 3.3.13.23 Install backing strip (paragraph 3.3.11) on top of spar tubes over filler longos (paragraph 3.3.10).

3.3.13.24 Remove spar broom (paragraph 3.3.5) from hardback, brush bushing surface with paragraph 3.2.9 resin and install over spar longo on flanged bushing. Fair step-tapered ends of broom longos with milled fiber. Caution: Do not allow milled fiber to lift tray. Use flange bushing holding tool to compress fiber.

○ 3.3.13.25 Remove spar longo assembly (paragraph 3.3.4) from hardbacks using carrying strips and install with flange bushings in mold recess and longo trays fitted to mold. Line up trailing edge of longo with locators. Fill tray cavity with paragraph 3.2.4 milled fiber. Caution: Do not allow milled fiber to lift tray. Note: Install clamp fixture to hold down bushings.

○ 3.3.13.26 Install root-end reinforcement laminate (paragraph 3.3.6) with the big side up, taper steps facing down. Note: Fill cavity around bushing with paragraph 3.2.4 milled fiber.

○ 3.3.13.27 Fold skin and de-icer cap over upper surface and smooth out.

3.3.13.28 Trim skin back to the mold depression and discard excess material.

3.3.13.29 Place a single layer of paragraph 3.2.15 aluminum screen over the entire area of upper mold half.

○ 3.3.13.30 Close mold.

3.3.13.31 Verify full contact of the mold flanges.

○ 3.3.13.32 Place upper half of mold press over mold blocks and lock in place.

○ 3.3.13.33 Pressurize press to 50 to 55 psig.

○ Indicates points that must be signed off by Quality Control Inspector.

○ 3.3.13.34 Pressurize the spar tubes and external mold tubes to 5 to 10 psig simultaneously (pressure lines manifolded together).

○ 3.3.13.35 Cure the blade according to the following schedule and record temperature, pressure, and time through cure cycle.

3.3.13.36 Pressurize internal spar tubes to 35 psig — two cycles over a 10-minute period. Maintain pressure to 30 to 35 psig. Note: Measure pressure at dead end of mandrels. Pressure readings should be same within gage tolerance.

○ 3.3.13.37 Hold 30 to 35 psig pressure in the spare tubes and 50 to 55 psig in the mold tubes. Raise mold temperature to 130° to 150°F. Use separate air source to pressurize the internal spar tubes and mold tubes.

○ 3.3.13.38 Hold the 130° to 150°F temperature for 4 to 6 hours.

○ 3.3.13.39 Increase mold temperature to 170° to 190°F and maintain for two hours.

○ 3.3.13.40 Increase the mold temperature to 230° to 250°F, hold mold temperature and maintain internal spar tube pressure at 30 to 35 psig and mold tube pressure at 50 to 55 psig for two hours.

3.3.13.41 Turn off heat to mold and reverse internal spar tube pressure. After pressure in spar tubes has been completely depleted, release mold pressure.

○ 3.3.13.42 When the mold reaches 150°F, release the mold frame locks, remove the upper mold frame, and open the mold.

3.3.14 Final Assembly

○ 3.3.14.1 Check the Barcol hardness of blade surface at the root, tip, and midspan locations, top and bottom, over the spar cap area. Record these measurements in Table D-VI.

○ 3.3.14.2 Fill No. 1, 2 and 3 spar tube cavities 6-1/2 to 7 inches deep from the root end with milled fiber/epoxy (paragraph 3.2.9). Fill No. 4, 5 and 6 tube cavities with syntactic foam (paragraph 3.2.11) 1/4 + 1/16-inch deep from root end and 1/4 ± 1/16-inch deep from the tip end. Use end dams to trap fillers.

○ Indicates points that must be signed off by Quality Control Inspector.

○ 3.3.14.3 Remove winding shafts and polyethylene bags from all spar tubes. Trim blade and verify dimensions per drawing.

○ 3.3.14.4 Laminate a tip area tab, in place, from three plies of paragraph 3.2.2 kevlar fabric with paragraph 3.2.9 resin.

○ 3.3.14.5 Install a tip closure rib in position with paragraph 3.2.9 resin.

○ 3.3.14.6 Install a root closure rib in position with paragraph 3.2.9 resin.

○ 3.3.14.7 Drill bleed holes through tip closure rib into <u>all</u> spar tubes. Cure blade at 180° to 200°F for two to three hours.

○ 3.3.14.8 Remove excess flash on laminates and maintain drawing requirements. Chase all threads in the tip weights.

3.3.15 <u>Final machining</u>.

○ 3.3.15.1 Machine the blade root bushings in accordance with drawing. Additional specific details are described in the following paragraphs.

○ 3.3.15.2 All machining shall be done WITHOUT liquid cutting lubricants.

○ 3.3.15.3 Apply polyurethane leading edge abrasion strip (activate adhesive with MEK).

3.3.16 <u>Painting — entire blade — excluding erosion strip</u>.

3.3.16.1 Wipe paragraph 3.2.21 pinhole filler onto the surface with clean rags, rubbing filler into voids with a circular motion. Allow to stand until the residue turns white and dry. Then wipe off excess material with a clean wiper cloth.

○ 3.3.16.2 Spray 1-mil thick paragraph 3.2.22 sanding surfacer on the blade surfaces. Air-dry for 1 hour at ambient conditions followed by 1 hour at 150° to 180°F.

○ 3.3.16.3 Sand the surfaces lightly with No. 200- to 400-grit sandpaper according to paragraph 2.6 specification. <u>Caution:</u> Be careful not to abrade the kevlar surfaces. Clean the sand surfaces with tack rags and then with aliphatic naphtha solvent.

○ Indicates points that must be signed off by Quality Control Inspector.

○ 3.3.16.4 Apply one coat, 0.8- to 1.2-mil thick, of paragraph 3.2.24 primer. Air-dry for 3 to 4 hours at ambient condition.

○ 3.3.16.5 Spray blade surfaces 0.8 to 1.0 mil thick with paragraph 3.2.23 black paint.

○ 3.3.16.6 Air-dry for 6 to 8 hours at ambient conditions.

3.3.17 <u>Final inspection</u>

○ 3.3.17.1 Inspect blade for completion in accordance with drawing.

○ 3.3.17.2 Weigh the blade and record its weight in Table 24.

3.3.18 <u>Balance</u>

○ 3.3.18.1 Static balance blade to master blade and record.

○ 3.3.18.2 Dynamically balance blade to master and record.

4. QUALITY ASSURANCE PROVISIONS

4.1 <u>Responsibility for inspection.</u>

The supplier of all basic materials used in the CMRB glade shall be responsible for assuring their quality. The balde shall be responsible for the quality of all processed components.

The blade manufacturer's inspectors shall be responsible for selecting rolls of dry filaments to achieve the dry weight control defined in the footnote to Table A-I. They shall also be responsible for ascertaining the filament/resin weight ratio for each blade element, as well as the weight of each tubular or longo element fabricated by the WFW process and for maintaining the weight record (Table 24).

The blade manufacturer's inspectors shall be responsible for seeing that all elements of the blade are properly wound, assembled, and finished.

Paragraph 3.3 indicates inspection points that must be signed off.

○ Indicates points that must be signed off by Quality Control Inspector.

TABLE 24. WEIGHT RECORD FOR BLADE S/N

Item No.	Part Name	Tool Weight (tare)	Tool Weight (postwind)	Component Weight (as measured)	Weight Limits Pound	Winding Length (in.)
1	Outer Skin	____	____	____	____	____
2	Spar Longo Upper Fwd	____	____	____	____	____
3	Spar Longo Upper Aft	____	____	____	____	____
4	Spar Longo, Lower Fwd	____	____	____	____	____
5	Spar Longo, Lower Aft	____	____	____	____	____
6	Spar Broom Longo Pair, Upper	____	____	____	____	____
7	Spar Broom Longo Pair, Lower	____	____	____	____	____
8	Root End Reinforcement	____	____	____	____	____
9	TE Longo	____	____	____	____	____
10	LE Longo	____	____	____	____	____
11	Spar Tube No. 1	____	____	____	____	____
12	Spar Tube No. 2	____	____	____	____	____
13	Spar Tube No. 3	____	____	____	____	____
14	Spar Tube No. 4	____	____	____	____	____
15	Spar Tube No. 5	____	____	____	____	____

TO BE DETERMINED

Finished Blade Weight ________ lb

Barcol Hardness, Spar Area

Top Surface		Bottom Surface	
Root	________	Root	________
Midspan	________	Midspan	________
Tip	________	Tip	________

FLIGHT TEST

1.0 INTRODUCTION

The composite main rotor blades (CMRB) were designed as a replacement for the metal main rotor blades (MMRB) on the U.S. Army/Hughes AH-64 Advanced Attack Helicopter. This report discusses the flight testing, results, and conclusions of the MM&T phase of the CMRB development.

CMRB MM&T flight tests began in August 1980. This test effort (Reference 9) resulted in the accumulation of data concerning track and balance, rotor stability, envelope expansion, and tethered hover. Two significant problems were revealed during the testing in 1980. One, skin-rib blade delamination of the outboard swept tip section which was satisfactorily repaired to continue testing and two, high blade torsion and pitch link loads. A decision to refine the blade design was made at this time.

MM&T flight testing resumed in September 1982 and continued to July 1983 after the CMRB redesign.

The remainder of this section addresses the various tests conducted during and after September 1982.

2.0 TEST OBJECTIVE

The test objective was the evaluation of the CMRB installed on the YAH-64 Advanced Attack Helicopter. This was to be achieved via a limited flight load evaluation, a limited flying qualities survey, and a limited vibration survey. Eighty percent of the YAH-64 flight envelope, developed with the MMRB installed, was to be demonstrated.

During CMRB envelope expansion the vibration characteristics in the high speed regime were found to be considerably higher than those of the MMRB equipped YAH-64 for similar flight conditions. This resulted in a test objective change. The remainder of the MM&T flight test program was conducted to determine the cause of the vibration problem.

3.0 TEST METHODS

Three distinctly different types of tests were performed and the methods used are described as follows.

3.1 Ground Tests. The purpose of the ground tests were to demonstrate the stability of the rotor system. These tests were performed by varying

rotor RPM from 100 to 120 percent N_R at various collective settings while electronically stirring the cyclic in an advancing sequence at the frequency which exhibited the greatest response.

3.2 Flight Tests. The flight tests were to be conducted in two parts. One, initial shake down and follow-on CMRB envelope expansion and two, a limited flight load evaluation, limited flying qualities survey and limited vibration survey. As previously mentioned, the latter portion of the flight testing was modified to vibration diagnostic testing.

3.3 Vibration Diagnostic Tests. The vibration diagnostic tests consisted of variations on both CMRB and MMRB configurations. The configuration variations are described in detail in paragraph 7.3.3. To evaluate the different blade configurations and establish cause and effect relationships between blade loads and airframe vibration the following test method was implemented. Considerable effort was spent in rotor tracking and balancing in the 140 to 164 KTAS regime. Once properly tracked and balanced, vibration and loads were measured at 60, 80, 100, 120, 130, 140, 150, 155, 160, 164 KTAS while maintaining an altitude of 5000 feet (density). For some configurations, pull-ups and turns, 140 KTAS, 2.0 g, 5000' Hd were also conducted. These maneuvers were performed to evaluate the configuration changes in terms of blade loads.

4.0 INSTRUMENTATION

The required mandatory measurements, alternates, and measurements requiring real-time monitoring are listed in Reference 10.

5.0 CALIBRATION REQUIREMENTS

The various measuring, testing, recording, transmitting, and receiving equipment was calibrated per MIL-Q-9858A, Quality Program Requirements, and MIL-STD-45662A, Calibration System Requirements. The range of the calibrations were as follows:

Loads and Forces - Sufficient to establish the linear portion of the curve

Positions - 100% of full travel

Pressures, temperatures, RPM, rates and accelerations - 100% of full scale

6.0 DATA ACQUISITION, REDUCTION AND ANALYSIS

Data acquisition and reduction were performed using the airborne data acquisition system, mobile data acquisition system and the fixed base data reduction center described in Reference 11. Analysis was performed using spectral techniques and evaluating data output in the form of time histories, frequency spectrums, and harmonic tables.

7.0 TEST RESULTS

7.1 Ground Tests. Ground testing was performed as previously described and defined by Test Plan CMRB 79-027 (Reference 9) and adequate rotor stability was demonstrated.

7.2 Flight Tests. Initial shakedown and CMRB envelope expansion flights were performed and the limited flight load survey was partially completed The following points were obtained:

Paced forward, left and right sideward flight to 40 knots.

Paced rearward flight to 30 knots.

50 to 164 KTAS at 5000' Hd.

Right and left lateral accelerations 0-40-0 at normal, moderate and rapid rates.

Right and left turns, 80, 100, 120, 140 KTAS to 2.2 g's, 5000' Hd.

Right and left turns, 155 KTAS, 1.7 g's, 5000' Hd.

Pullups, 80, 100, 120, 140 KTAS, to 2.2 g's 5000' Hd.

Pullups, 155 KTAS, 1.3 g's, 5000' Hd.

Pushovers, 80, 100, 120, 140 KTAS, 0.5 g's, 5000' Hd.

Sideslip, ±8°, 100, 120, 140 KTAS, 5000' Hd.

Partial power descents, 120, 140, 155, 164 KTAS.

Autorotations, 80, 105, 120 KTAS.

Decelerations, normal to moderate, 85 ⟶ 0 KTAS.

No significant load problems were encountered. During these flights minor irregularities were observed in some chordwise and pitch link measurements.

The chordwise problem was traced to a faulty gage and the pitch link problem cleared up with subsequent configuration changes.

7.3 Vibration Diagnostic Tests

7.3.1 The Vibration Problem. The vibration environment in the crew stations with the composite main rotor blades installed was initially found to be significantly higher than the vibration environment with the metal main rotor blades installed during forward flight above 130 KTAS. Measured 4P levels at the pilot seat (vertical) were somewhat higher during low speed flight, 30-50 knots, and during maneuvers and significantly higher, at times twice MMRB levels, in the high forward flight regime.

7.3.2 Vibration Problem Resolution. The first task toward resolving the vibration problem was a CMRB-MMRB comparison. This included geometric and physical property differences, as well as diagnostic flights including flights with rpm and collective pitch variations. Equivalent flights were conducted with metal blades so that a direct comparison of blade loads could be made to establish cause-effect relationships. In addition, blade natural frequency determination tests were made with inputs to the rotor both rotating and non-rotating.

Geometrically and physically, the CMRB differed from the MMRB in the following areas. The CMRB blade root from station 52 to 84 did not present the same 2-D shape (see Figure 68). The tracking tabs on the CMRB were slotted every 10 inches whereas the MMRB tracking tabs were not. The CMRB incorporated a 9 percent symmetric swept tip versus the MMRB 6 percent swept tip.

Other differences were blade bow and chordwise weight distribution. The manufactured flapwise bow in the CMRB was three inches at midspan which equates to twelve inches of inherent droop. The MMRB has no flapwise bow. Inherent chordwise bow differed between CMRB and MMRB as depicted in Figure 69. The chordwise CG of CMRB is 27.9 percent, the design goal being 26 percent whereas the MMRB chordwise CG is 27.4 percent designed for 26.5 percent. The radial first moment distribution differed between CMRB and MMRB as shown in Figure 70. Distribution of the CMRB weight, 150.1 lbs vs the MMRB weight, 154.4 lbs is as shown in Figure 71. Spanwise CG difference, 159.2 in (CMRB) vs 157.4 in (MMRB) and torsional stiffness, MMRB 7 percent greater than CMRB were other significant differences.

In addition to the investigation of physical, geometrical and mass property differences, the measured loads for CMRB and MMRB were compared to establish cause and effect relationships. These differences can be summarized as follows.

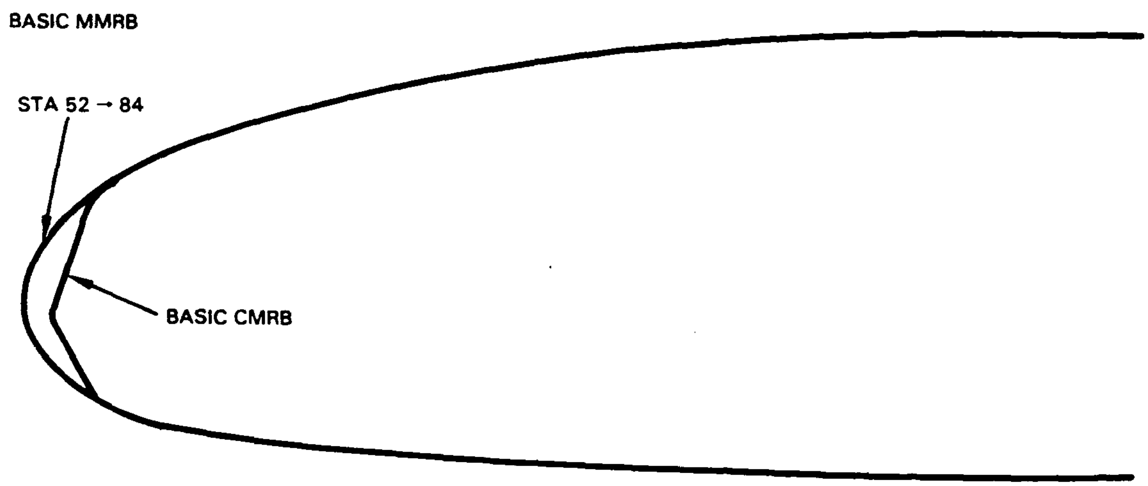


Figure 68. Cross sectional differences between CMRB and MMRB (Stations 52 through 84)

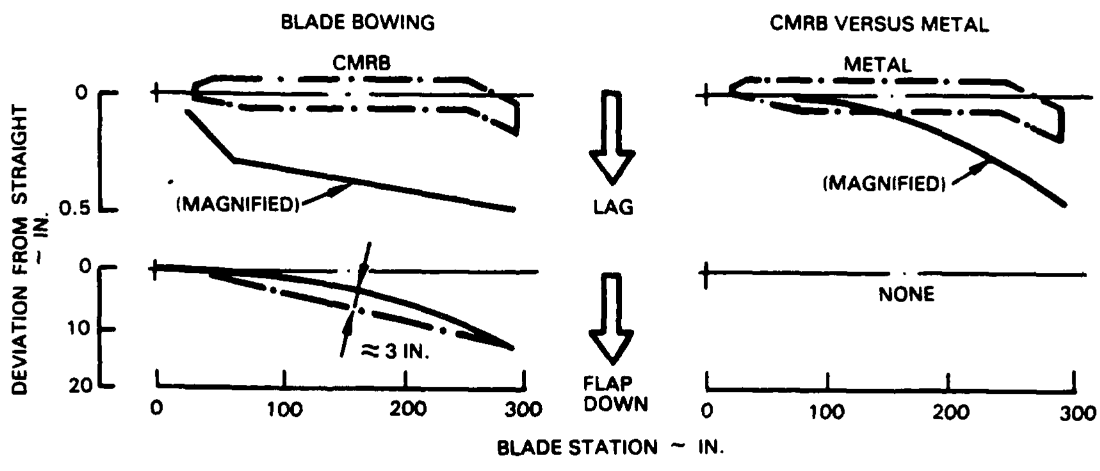


Figure 69. Built in blade bowing differences between the metal and CMRB

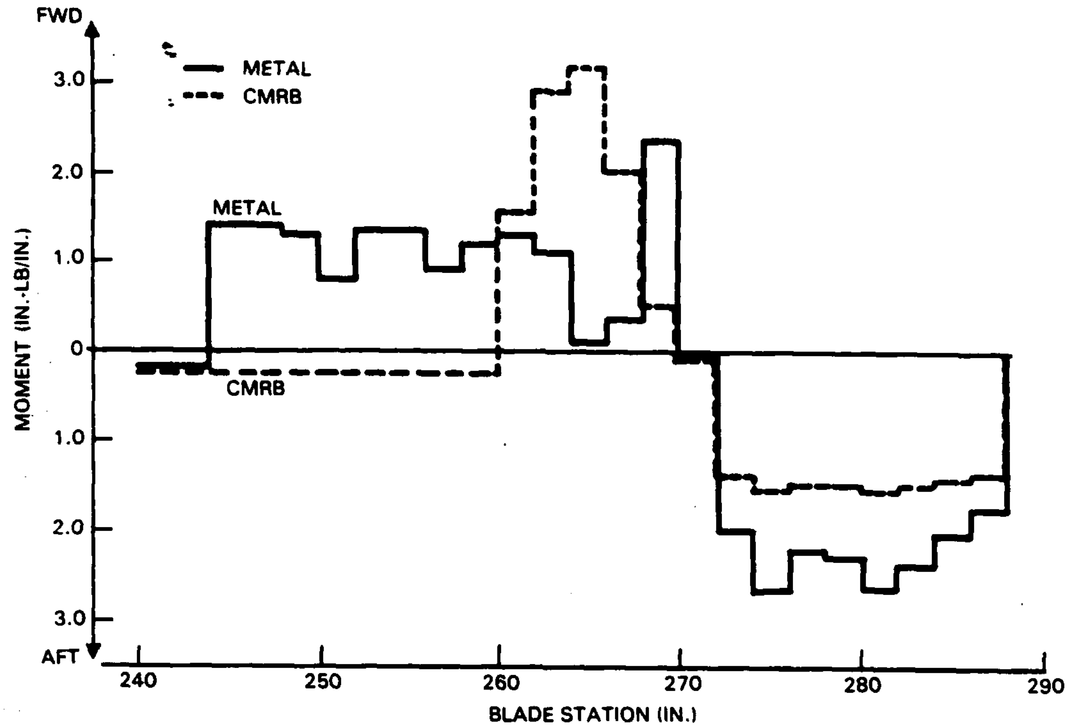


Figure 70. First mass moment differences in the tip area (metal and CMRB)

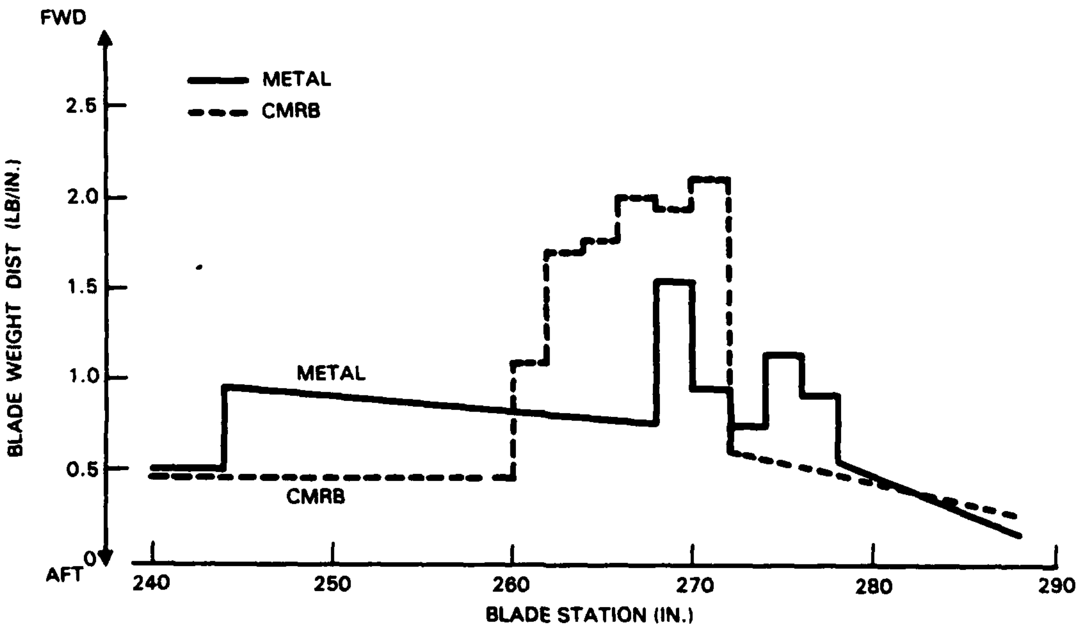


Figure 71. Tip blade weight distribution between the metal and CMRB

The blade torsion loads were generally higher for CMRB. This included pitch link and actuator loads. 4/rev torsion loads in particular were higher for CMRB.

The CMRB blades also demonstrated an increase in flapwise bending loads at station 28.75 on the pitch housing. In particular the 3/rev loads were higher for CMRB with smaller increases in 4/rev and 5/rev. Mast bending loads at 4/rev both in longitudinal and lateral direction were higher for CMRB. The 4/rev component of chordwise bending was higher for CMRB. An illustrated summary is shown in Figures 72 through 76. Also shown is the CMRB 6 percent data which was the final configuration flown.

7.3.3 Vibration Investigation Flights. Based on the detected differences several configuration changes were made and flight evaluations conducted. The following is a brief chronological description of these investigations. Figure 77 illustrates the vibration level (4P pilot seat vertical) associated with each configuration.

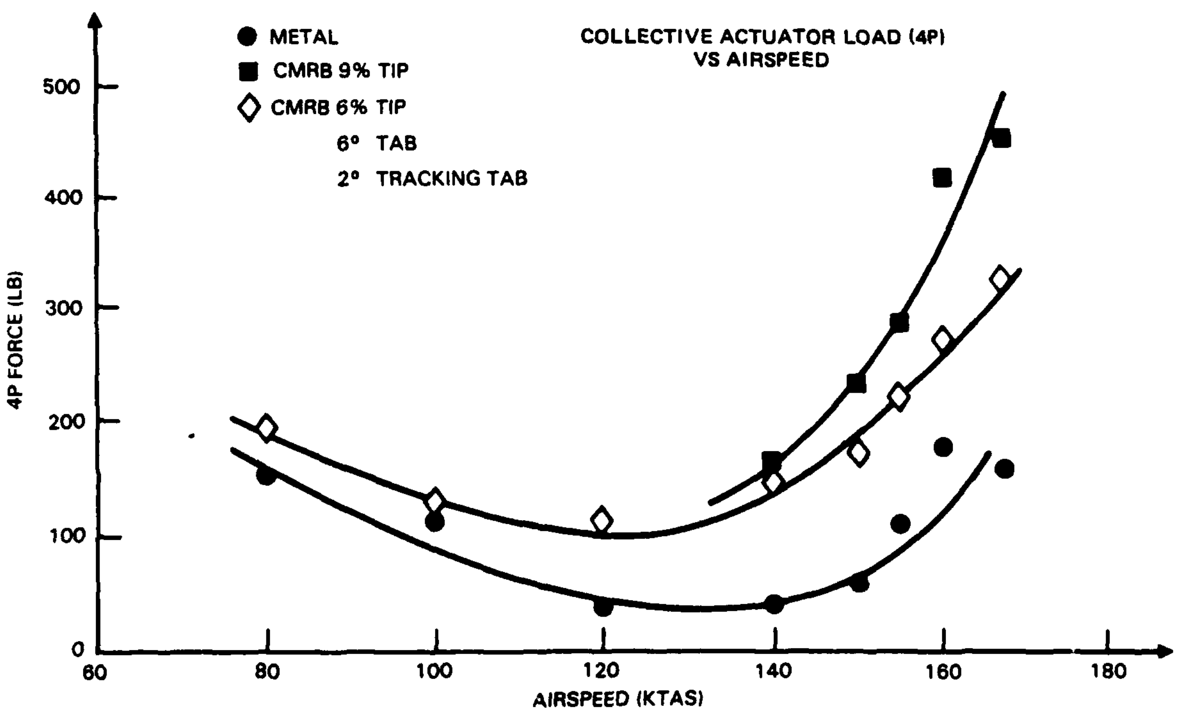


Figure 72. Collective actuator load versus airspeed (Sheet 1 of 2)

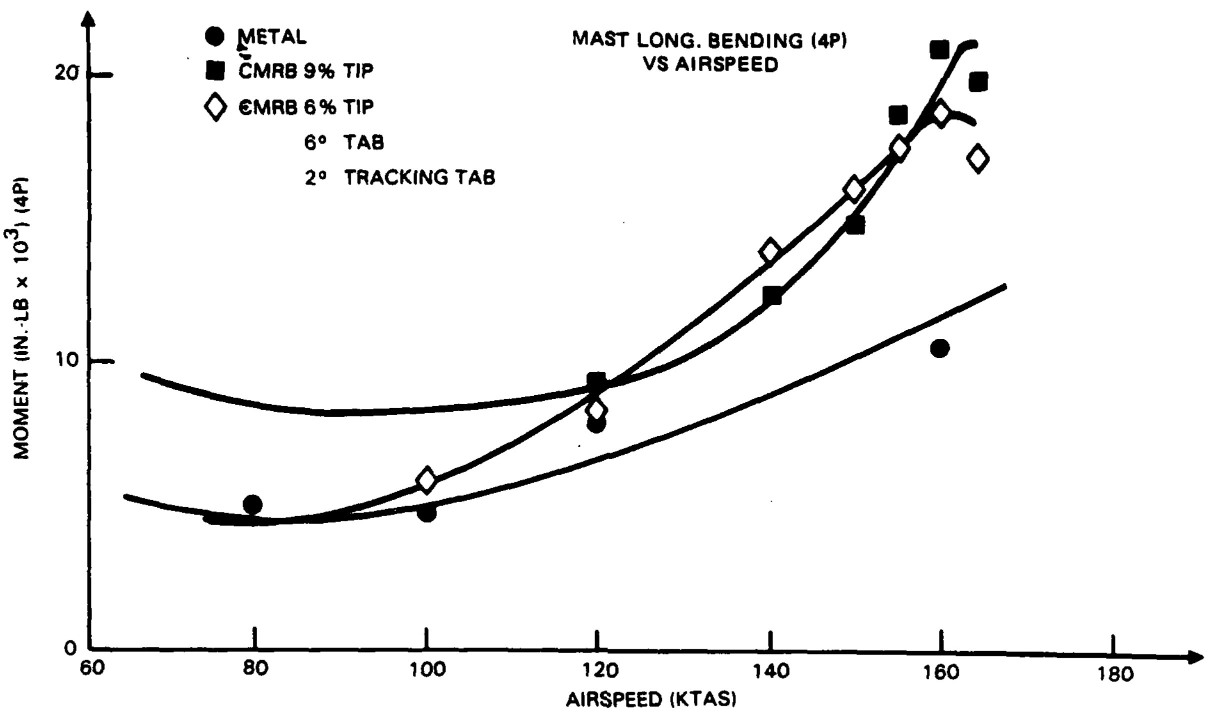
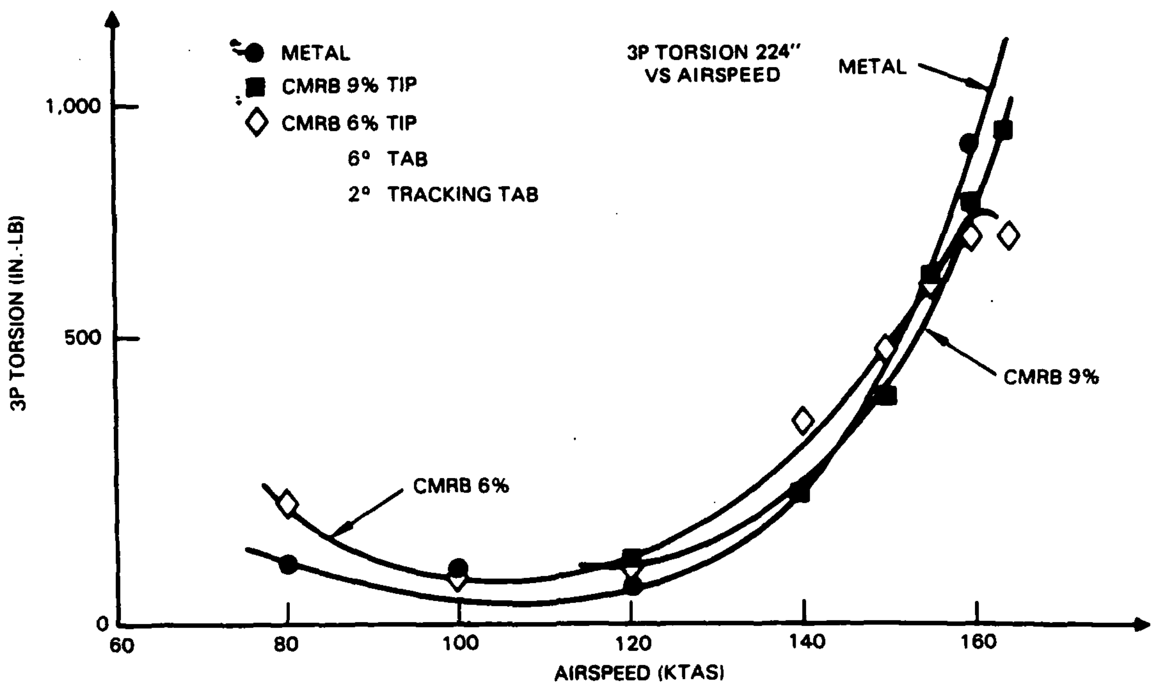


Figure 72. Collective actuator load versus airspeed (Sheet 2 of 2)



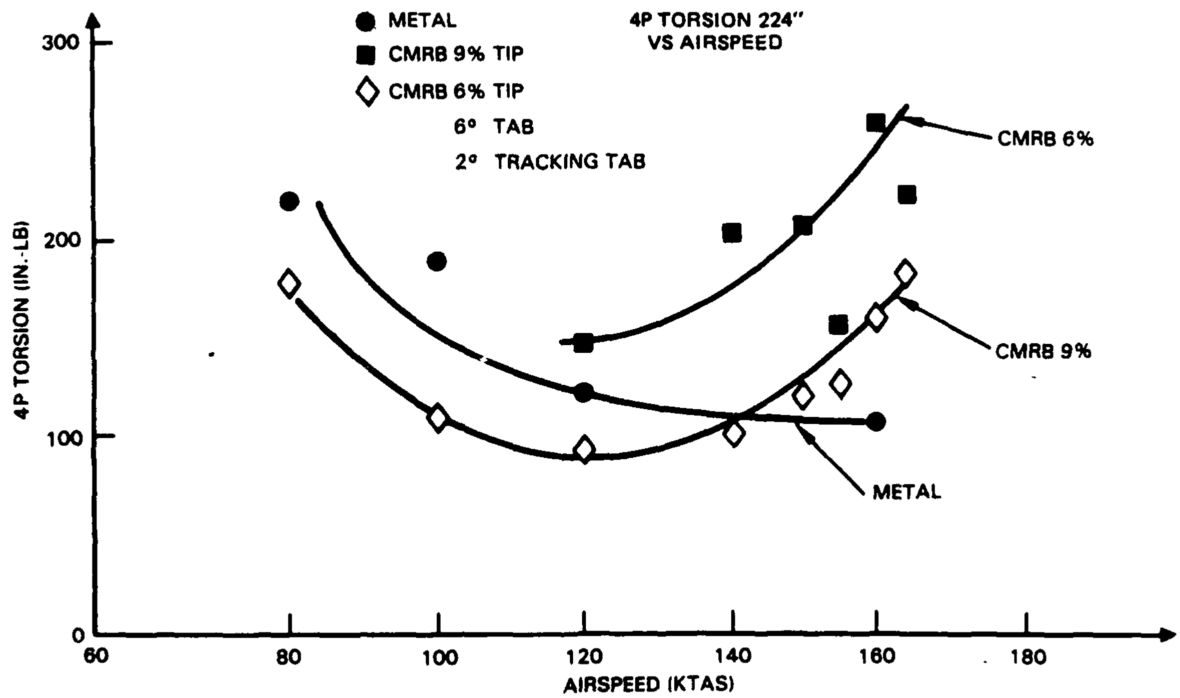


Figure 73. Torsion versus airspeed (station 224) (Sheet 1 of 2)

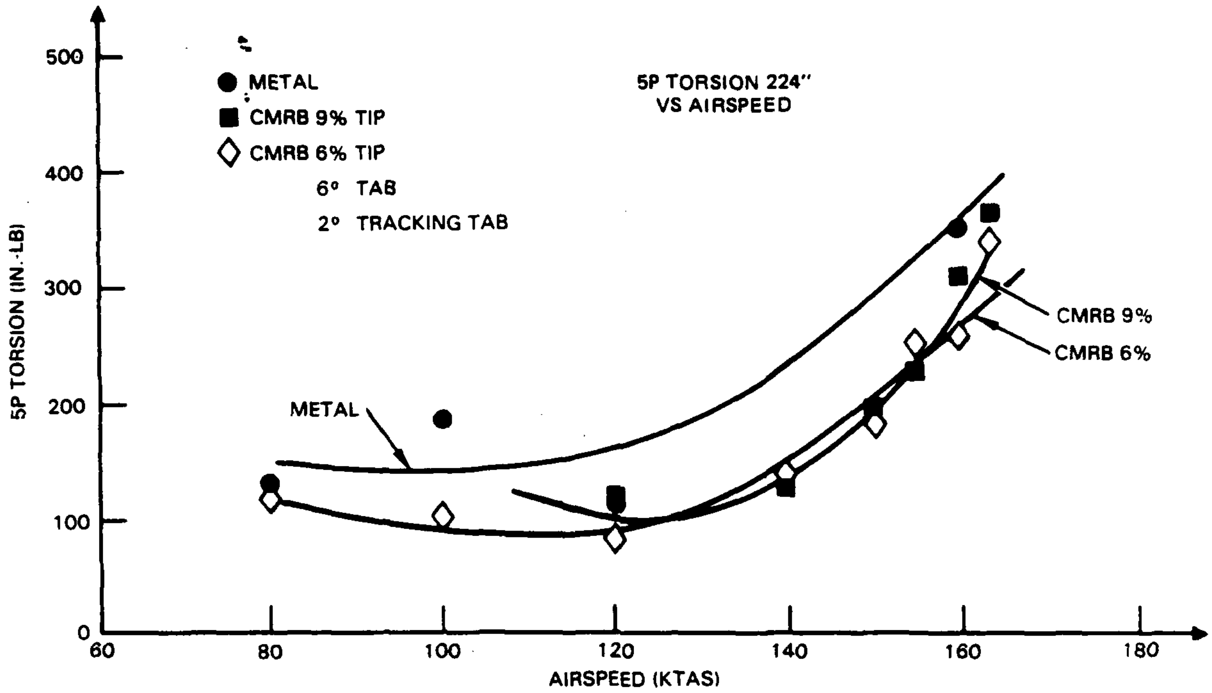


Figure 73. Torsion versus airspeed (station 224) (Sheet 2 of 2)

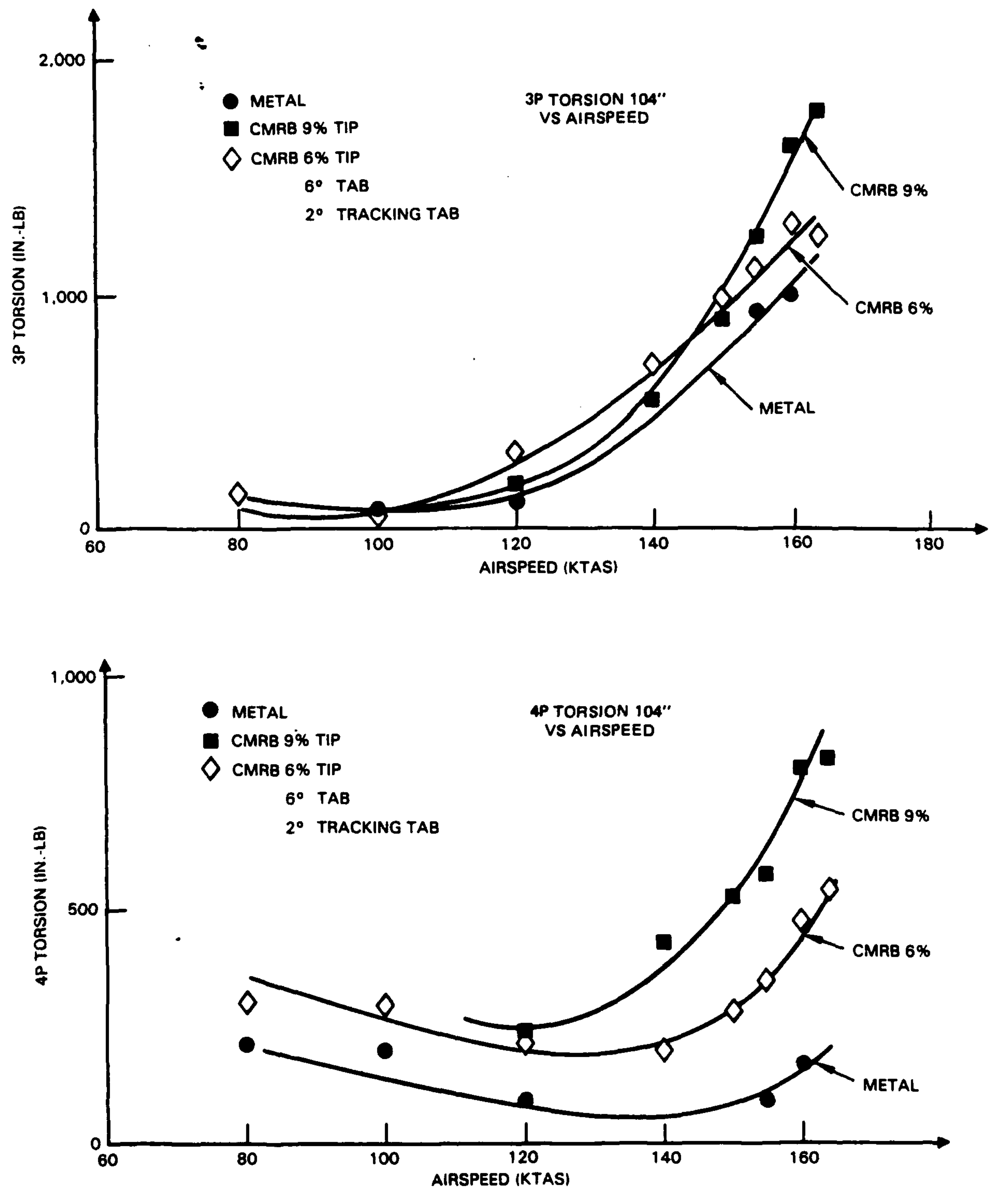


Figure 74. Torsion versus airspeed (station 104) (Sheet 1 of 2)

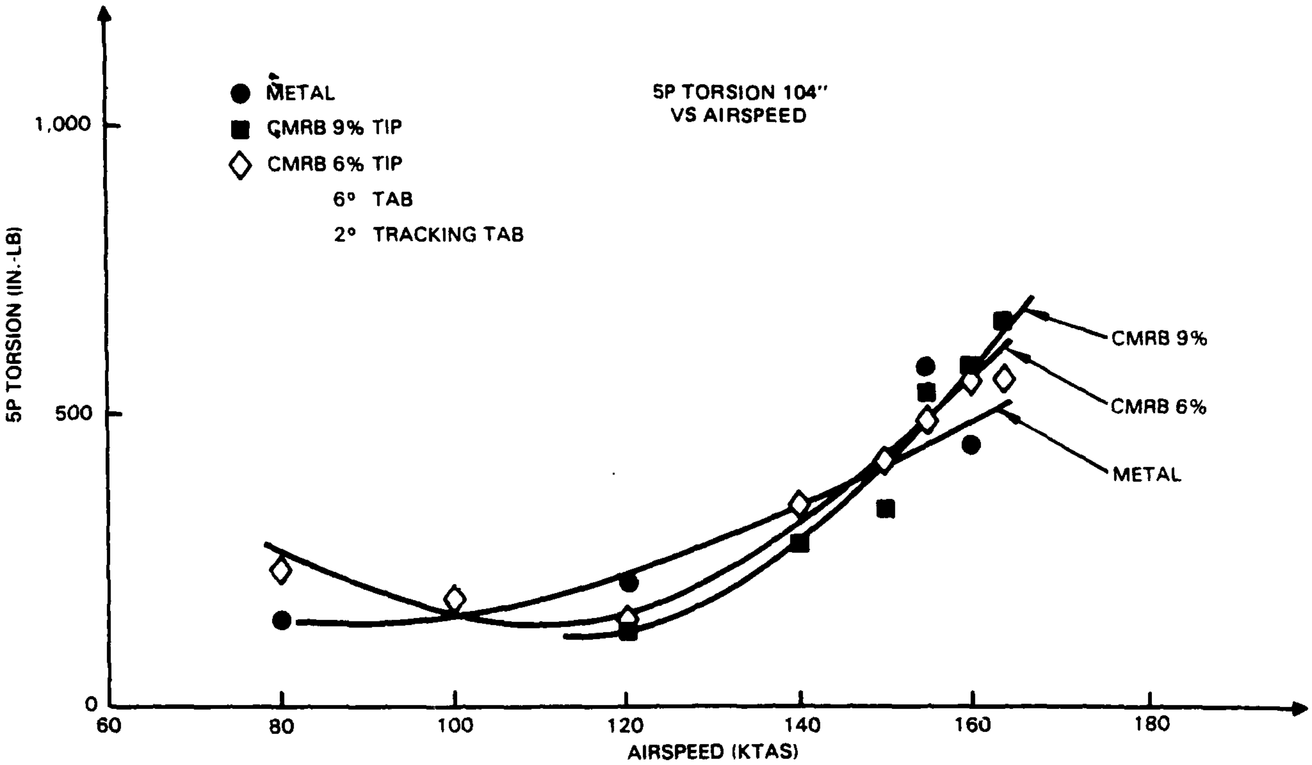
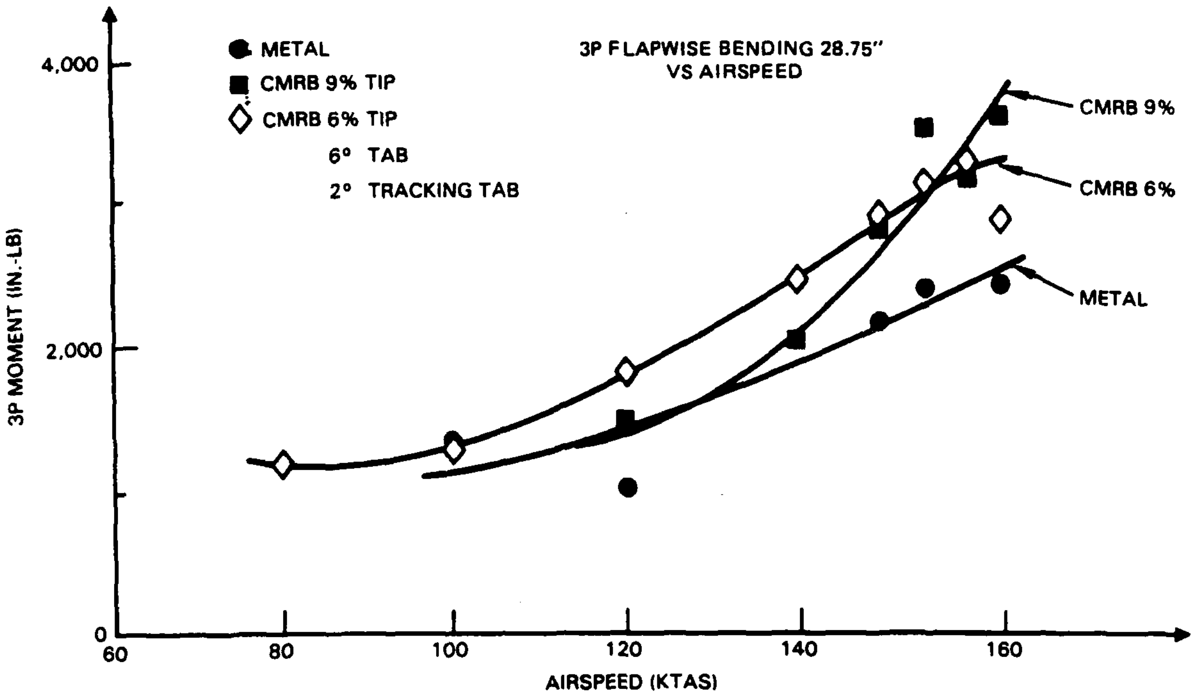


Figure 74. Torsion versus airspeed (station 104) (Sheet 2 of 2)



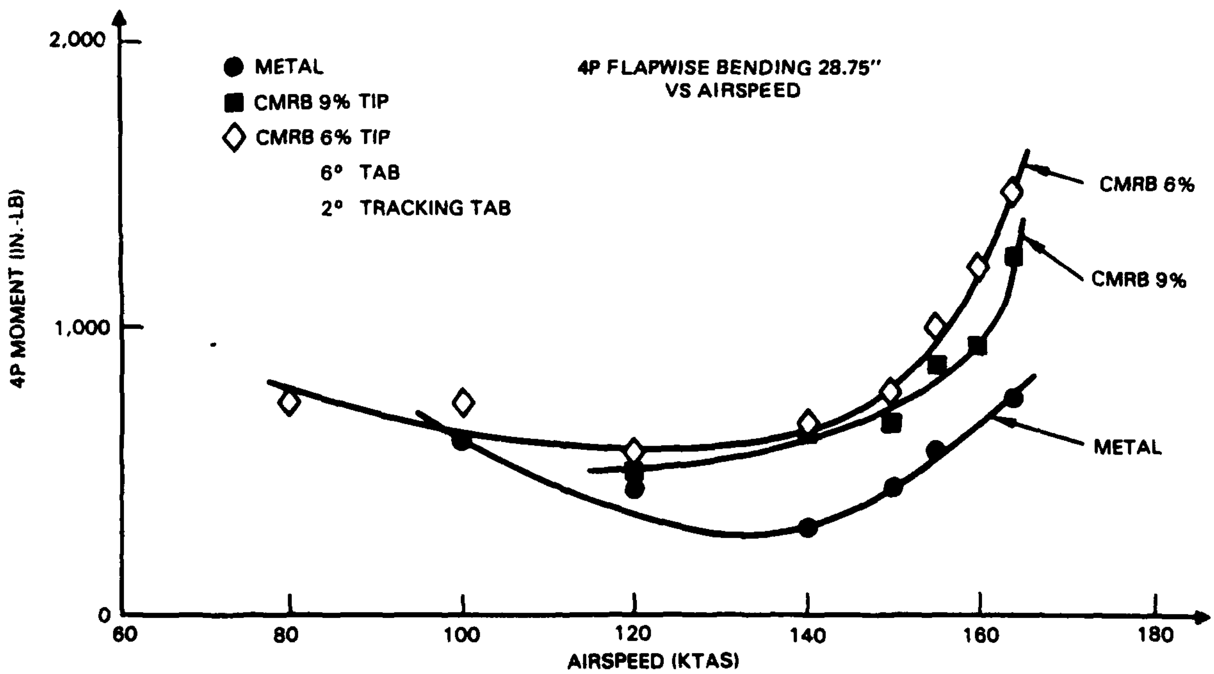


Figure 75. Flapwise bending versus airspeed (station 28.75)
(Sheet 1 of 2)

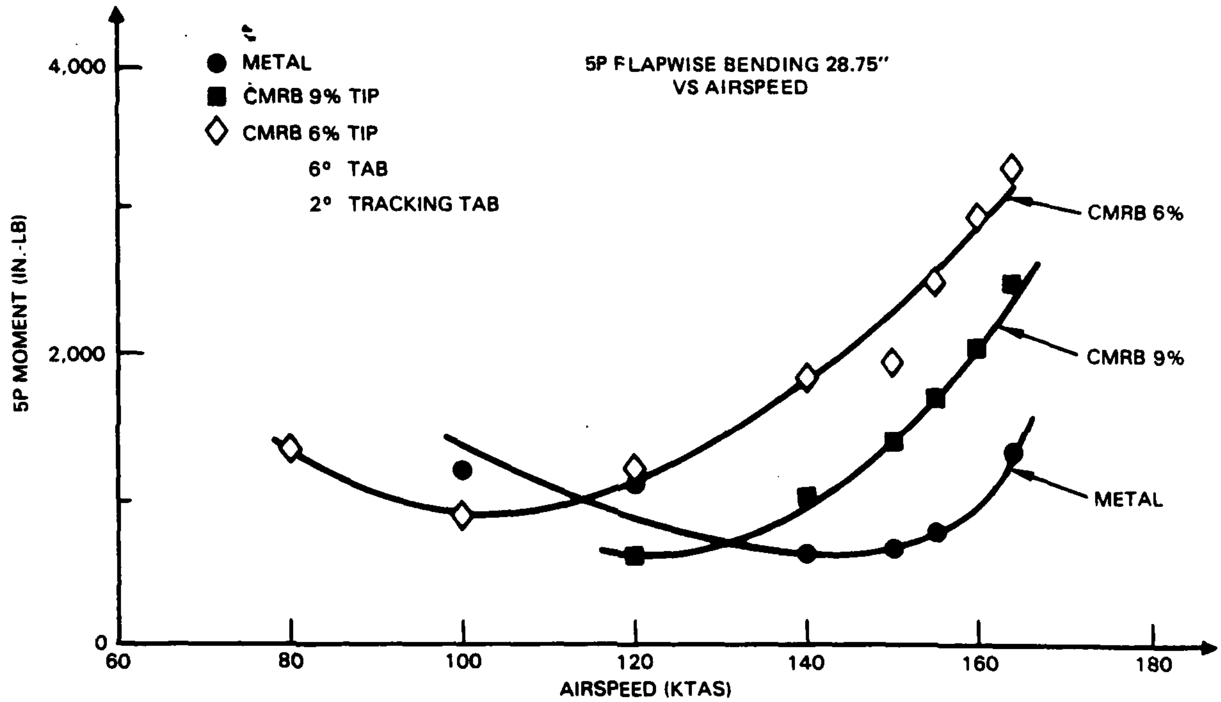


Figure 75. Flapwise bending versus airspeed (station 28.75)
(Sheet 2 of 2)

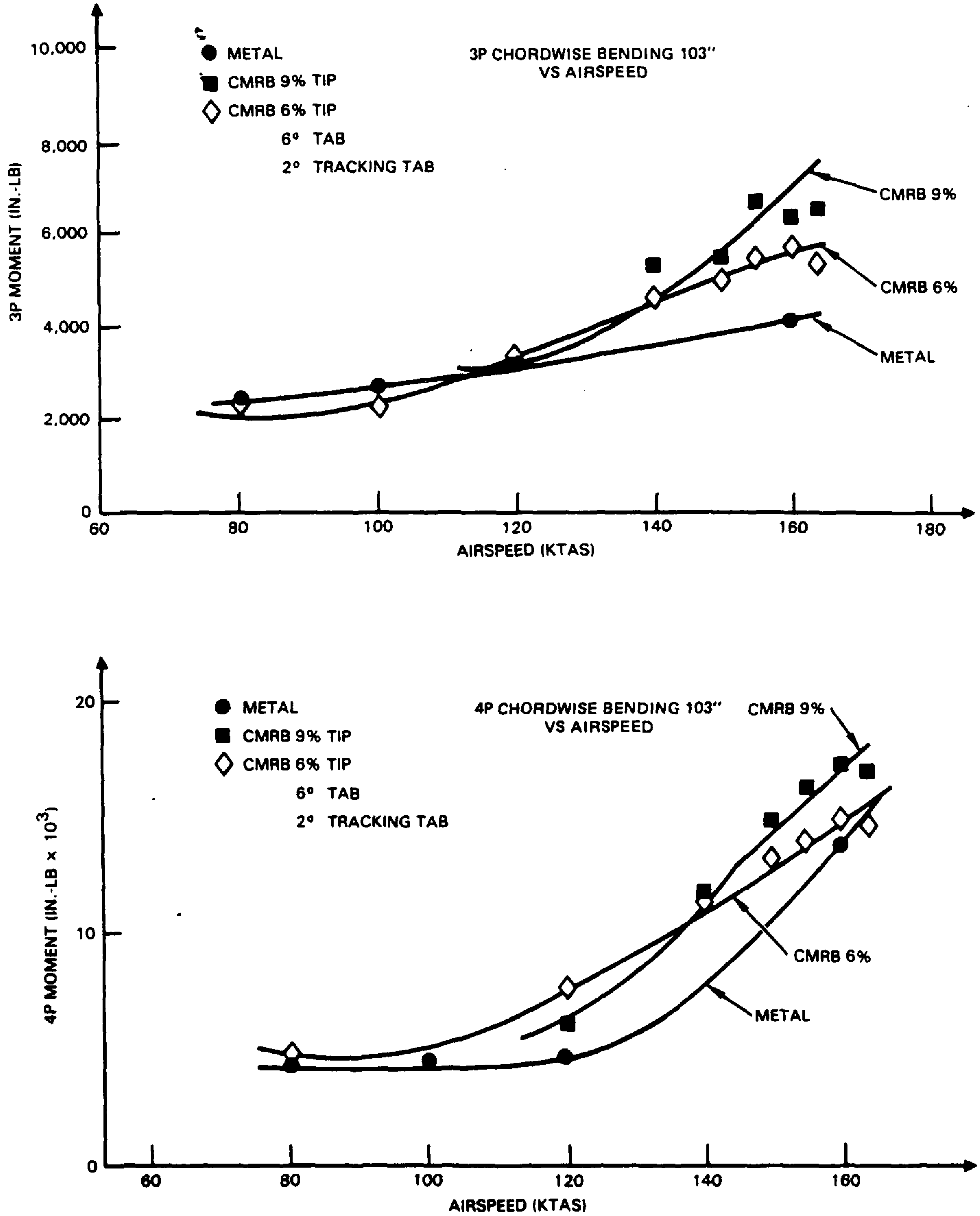


Figure 76. Chordwise bending versus airspeed (station 103)
(Sheet 1 of 2)

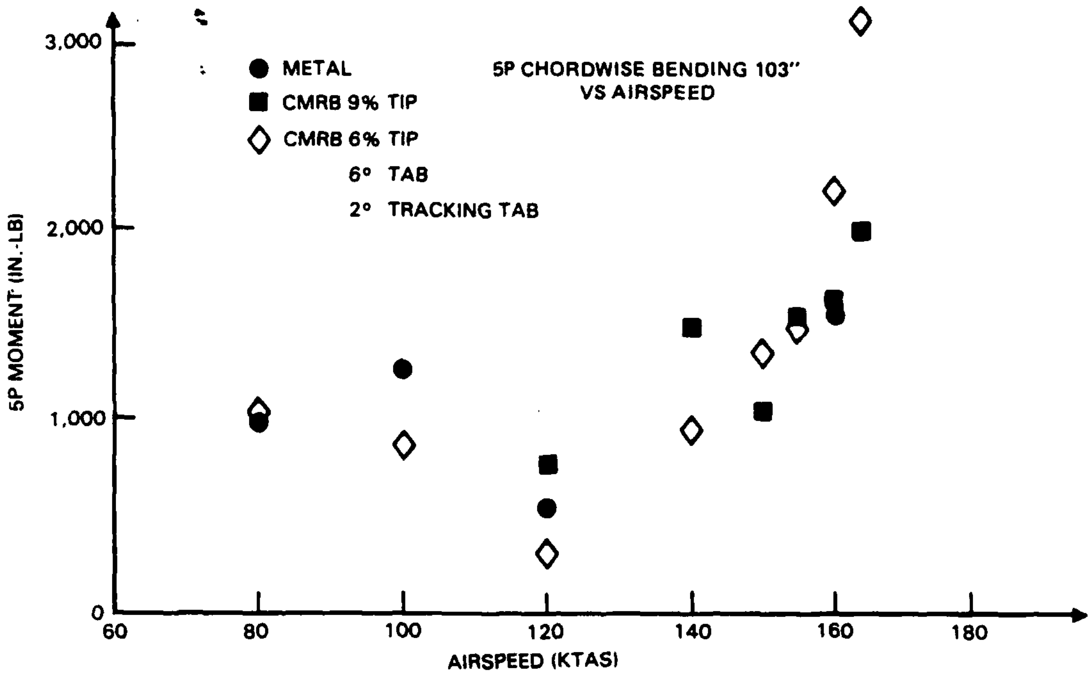


Figure 76. Chordwise bending versus airspeed (station 103)
(Sheet 2 of 2)

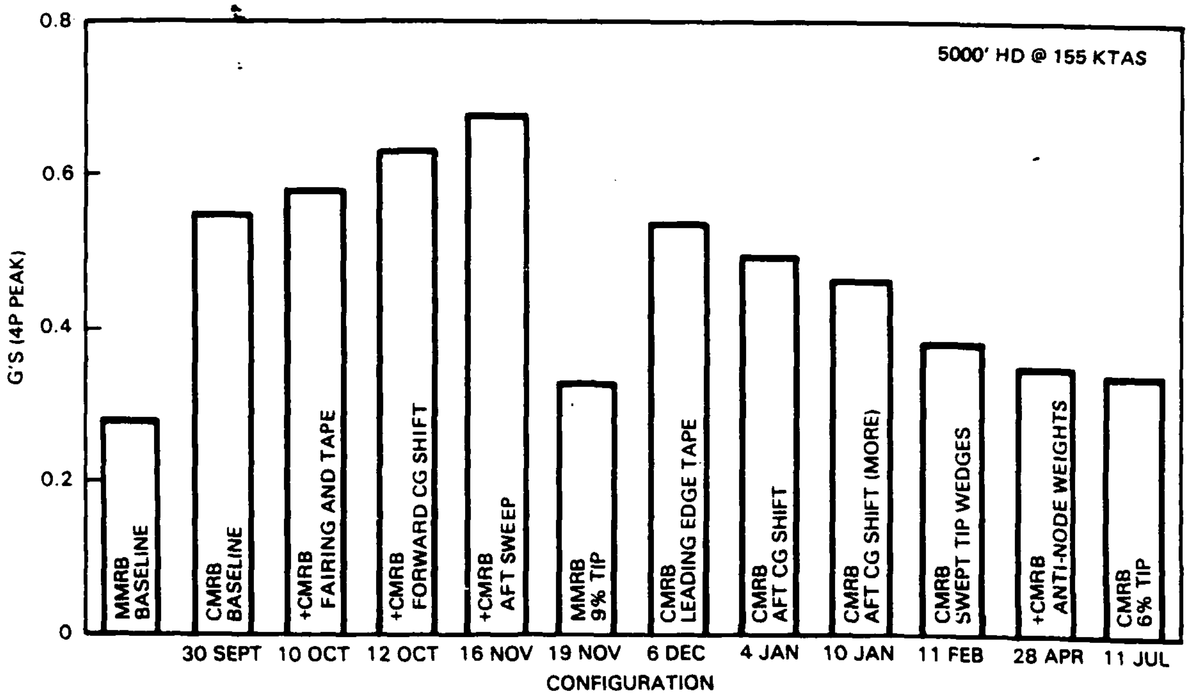


Figure 77. Pilot Seat Vertical Vibration Vs Configuration

It should be noted that one of the drivers for configuration change decisions was the pilot's perception of the vibration environment and his subsequent vibration rating. Figure 78 illustrates the pilot's vibration rating for each configuration as well as the vibration rating definition. It should be further noted that the pilot's vibration perception combines all harmonics as well as noise.

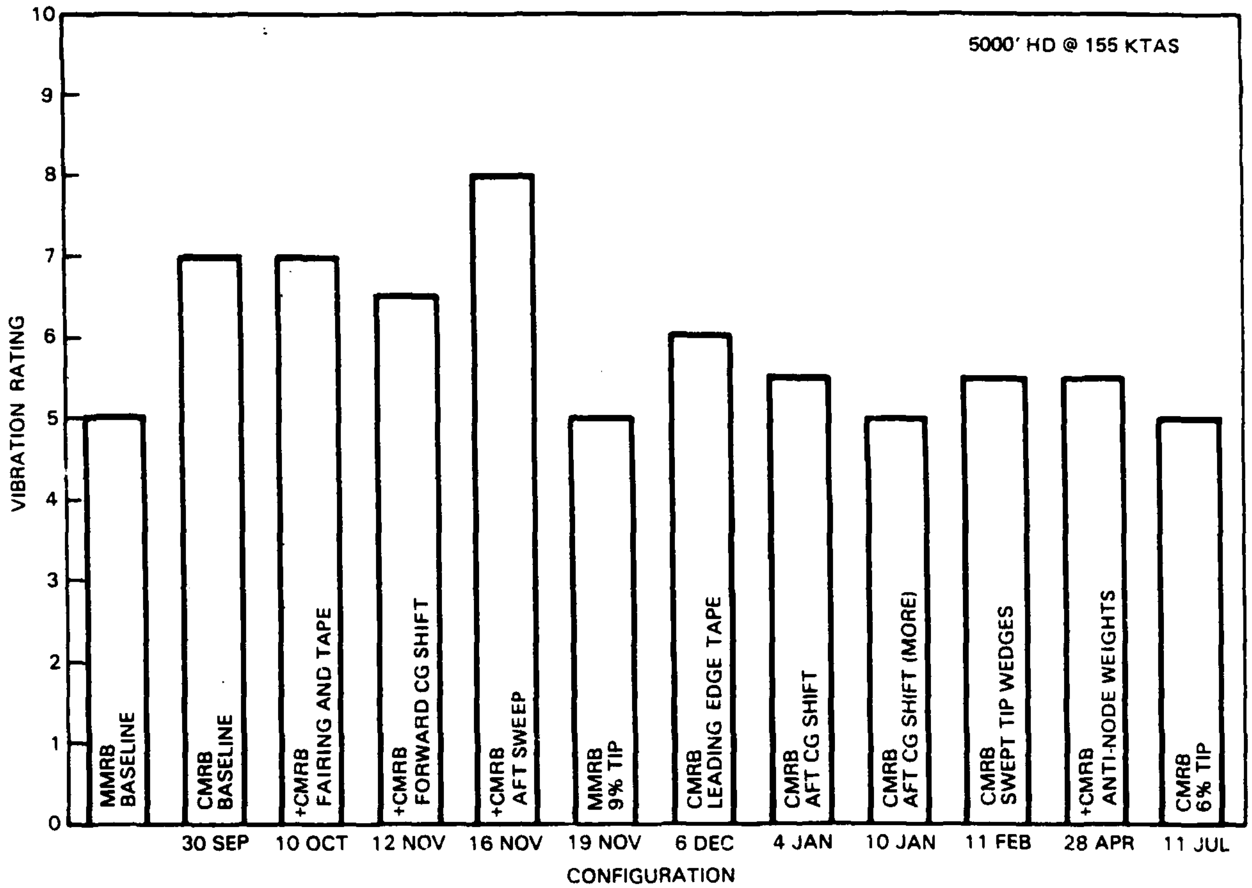
<u>29 Sep 82</u>

Initial CMRB shake down flight to 40 knots no problems.

<u>30 Sep - 12 Oct 82</u>

CMRB envelope expansion

High vibration environment detected in the high speed forward flight regime.



VIBRATION ASSESSMENT SCALE

RATING	TERM USED FOR DEGREE	DESCRIPTION
0	NO VIBRATION	
1 2 3	SLIGHT	NOT APPARENT TO EXPERIENCED AIRCREW FULLY OCCUPIED BY THEIR TASKS, BUT NOTICEABLE IF THEIR ATTENTION IS DIRECTED TO IT OR IF NOT OTHERWISE OCCUPIED.
4 5 6	MODERATE	EXPERIENCED AIRCREW ARE AWARE OF THE VIBRATION BUT IT DOES NOT AFFECT THEIR WORK, AT LEAST OVER A SHORT PERIOD.
7 8 9	SEVERE	VIBRATION IS IMMEDIATELY APPARENT TO EXPERIENCE AIRCREW EVEN WHEN FULLY OCCUPIED. PERFORMANCE OF PRIMARY TASK IS AFFECTED OR TASKS CAN ONLY BE DONE WITH DIFFICULTY.
10	INTOLERABLE	SOLE PREOCCUPATION OF AIRCREW IS TO REDUCE VIBRATION.

Figure 78. Pilot Vibration Rating Vs Configuration

10 Nov 82

Addition of inboard fairing and tracking tab slot tape to CMRB.

This modification consisted of a fairing added to the CMRB leading edge from station 52 to station 84 and to tape up the slots in the trailing edge tracking tabs. The logic behind this was as follows. The harmonic content between stations 104 and the pitch link suggested airflow in that area was not optimum, hence the leading edge fairing. A steady nose-up moment on the CMRB vs the MMRB steady nose-down moment suggested tracking tab ineffectiveness, hence the slot tape.

Flight test with this configuration resulted in a small degradation in crew station vibration environment and no significant change in steady torsional moment.

12 Nov 82

CMRB forward CG shift with fairings and tape.

This modification was to shift the CMRB chordwise CG forward 0.2 percent and accomplished by shifting 273.7 grams from the aft tip pocket to the front tip pocket and adding an additional 384.6 grams to the front tip pocket on each blade. It was suggested that the CG-AC offset was the cause of the steady nose up moment and consequently the CG change was affected.

Flight test again showed a slight vibration degradation.

16 Nov 82

CMRB swept aft with fairings, tape and CG shift.

This modification swept all the blades aft 5.5 inches (at tip). Again, this was to provide a steady nose-down moment by placing the lift vector aft of the feathering axis.

Flight tests again showed a very slight vibration degradation. The fairings and tape were subsequently removed and the blades were swept forward to their original position.

19 Nov 82

MMRB fitted with 9 percent swept tips.

To establish if the CMRB vibration problems were due to 9 percent tip design compared to a 6 percent tip design for metal blades, this flight was conducted.

Flight tests showed a significant rise in vibratory torsional load, a significant drop in mast bending loads, and only a slight increase in the vibration environment. As the 9 percent tip modification also changed the weight distribution, no clear cause and effect relationship was established.

6 Dec 82

CMRB leading edge lead tape.

This modification moved the CMRB CG forward 0.6 percent by adding 3.4 lbs of lead tape to the leading edge from station 56 to station 270. Again, producing a steady nose-down moment by adjusting the CG-AC offset was the driver for this modification.

Flight tests showed a slight vibration environment improvement along with a slight loads improvement.

4 Jan 83

CMRB swept tip portion of CG shift.

733.5 grams were shifted from the forward pocket to the aft pocket. As virtually no improvement was seen by the forward CG shifts, the aft CG shift was accomplished per consultant recommendation whose logic was to bring the product of the second flapwise mode and the first mass moment closer to that of the MMRB.

Flight test showed a slight vibration environment improvement.

10 Jan 83

CMRB swept tip portion CG shift.

Weight was added to the aft portion of the swept tip to move the CG further aft.

Flight test showed minimal load and vibratory improvement. A large increase in 5/rev flapwise loading was observed.

11 Feb 83

Addition of 12° swept tip trailing edge wedges to CMRB.

Still in search of a steady nose-down moment to duplicate the MMRB, balsa wood wedges were attached to the lower trailing edges of the swept tip portion of the CMRB at a 12° angle.

Flight test results showed a steady nose-down moment was obtained and subsequent bending of the tracking taos to achieve a nose down moment distribution more like that of the MMRB was inconclusive as the 4/rev vibration levels decreased but the pilot vibration ratings increased. 5/rev flapping loads increased significantly with the wedges and tab bends.

28 Apr 83

Application of 5/rev anti-node weights.

Reduction of the 5/rev flapwise loads was the next step to detune the 5/rev flap response.

No significant changes resulted. The anti-node weights were subsequently removed.

The final configuration consisted of CMRB with 6 percent tip and bendable tabs in the blade swept portion. Funding for this program was provided from AQS (Airworthiness Qualification Specification) funds. A brief description is included for the sake of completeness.

11 Jul 83

CMRB with 6 percent swept tips.

A 6 percent symmetric swept tip with an adjustable trailing edge tab was installed on the CMRB.

Flight test showed a significant decrease in vibration and loads with this modification. The flight loads are virtually the same as those with the MMRB installed and the vibration environment is only slightly higher (see Figure 79). in high speed region. A comparison of this configuration to MMRB in low speed flight regime (30-50 kts) indicated that two blades are virtually identical. Pilot comments substantiated this observation.

Due to this configuration being almost identical to MMRB, it is recommended for production.

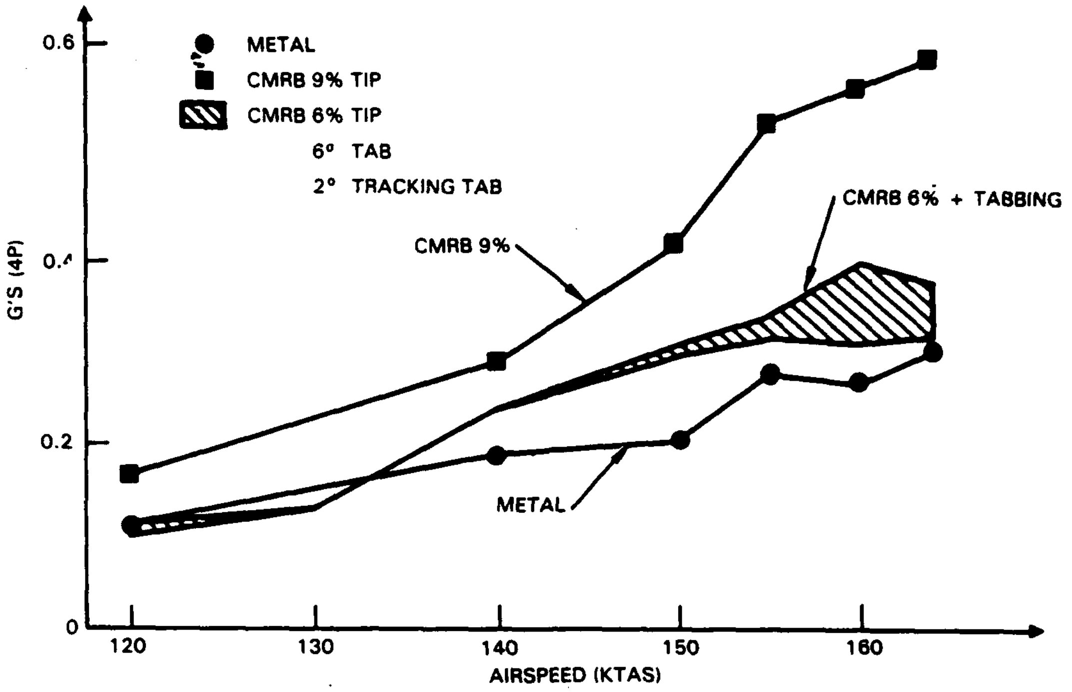


Figure 79. AAH CMRB pilot seat vertical vibration (4P) versus airspeed

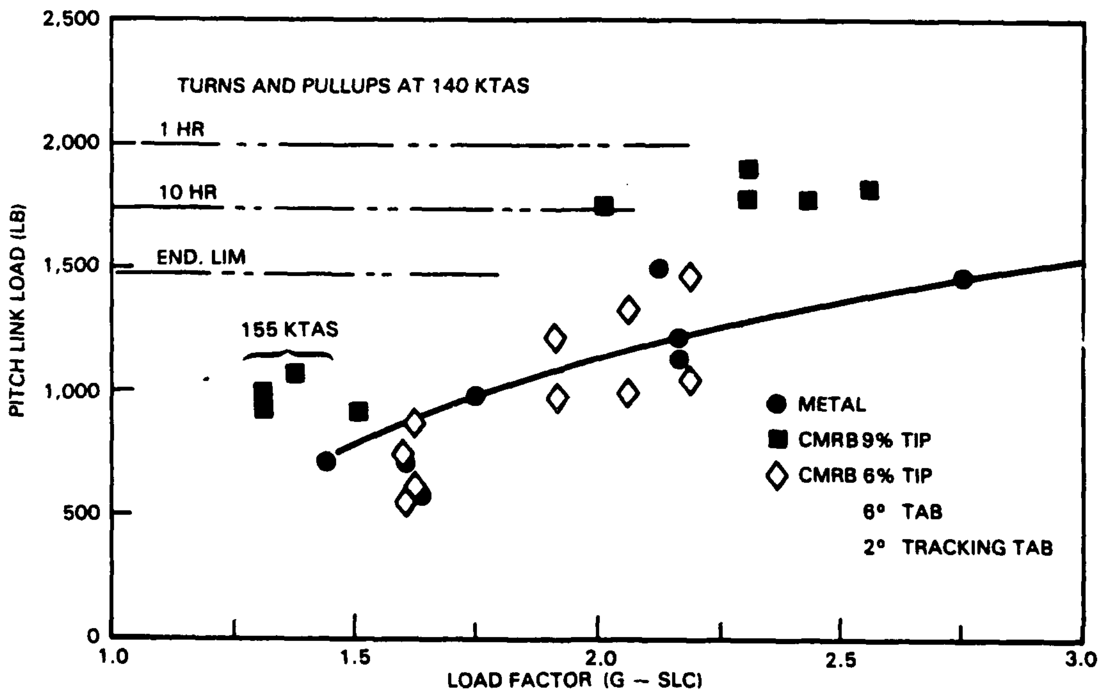


Figure 80. AAH CMRB cyclic pitch link load versus load factor

CONCLUSIONS

This MM&T program has demonstrated how advanced composites technology can be applied to the main rotor blade of the AH-64A helicopter to provide a rugged, reliable component at a significant cost saving. This was accomplished through refinement of the wet filament winding, cocure fabrication process, tailored especially to the CMRB and resulted in a blade that meets all of the design goals.

The structural design is complete, all tooling is available, whirlstand and laboratory tests and flight tests have been completed successfully.

The particular benefits that the CMRB offers in comparison with the currently existing metal main rotor blade are:

- 24.6 pound weight saving } shipset of four blades
- $194,300* cost saving } shipset of four blades
- $602* million overall production and life cycle cost saving for the fleet
- $380,000* fuel saving over the life of the fleet from reduced blade weight
- 20 foot per minute vertical rate of climb increase from reduced blade weight
- Improved reliability and maintainability

These are very powerful incentives for incorporating the CMRB on the AH-64A at the earliest possible moment.

*1981 dollars

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